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Informal Report

Meteorological Services Annual Data Report for 2016

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Table of Contents

Purpose.....	1
Background.....	1
Site	2
Instrument Towers	2
85-meter Tower.....	2
10-meter Tower.....	2
2-meter pole	3
Solar Base Station.....	3
Calibrations.....	3
Data Sets and Data Availability	4
Meteorological Data Recovery for 2015.....	4
Air Temperature.....	8
Barometric Pressure.....	26
Relative Humidity.....	32
Rainfall.....	41
Wind Direction and Wind Speed	51
2016 Solar Resource Data.....	84
Global Solar Radiation.....	84
Diffuse Solar Radiation.....	89
Direct Solar Radiation.....	89
Long-wave Far Infrared Radiation.....	89
LISF and NSERC Reference Pyranometers	89
References.....	133

List of Tables

Table 1a. 2016 Extremes and Totals.....	6
Table 1b. Historic Extremes	7
Table 2. Monthly Temperature Summary.....	10
Table 3. Historic Monthly Mean Temperatures (°C) for Brookhaven National Laboratory from 1949 to present (@ 2 meters).....	17
Table 4. Historic Monthly Mean Maximum Temperatures (°F) for Brookhaven National Laboratory from 1949 to present (@ 2 meters)	20
Table 5. Historic Monthly Mean Minimum Temperatures (°F) for Brookhaven National Laboratory from 1949 to present (@2 meters)	23
Table 6. Historic Monthly Precipitation for Brookhaven National Laboratory from 1949 to present (@ 2 meters)	48
Table 7. Average Daily Solar Irradiance (Global) at BNL by Month (W/m ²)	85

List of Figures

Figure 1. Average Daily Temperature taken at the 2 meter height at BNL for 2016	9
Figure 2. Daily Minimums and Maximums in Temperature taken at the 2 meter height at BNL for 2016.....	9
Figure 3. Monthly Mean Temperatures (°C) at Brookhaven National Laboratory for 2016.....	10
Figure 4. Air Temperature for the Month of January 2016	11
Figure 5. Air Temperature for the Month of February 2016	11
Figure 6. Air Temperature for the Month of March 2016	12
Figure 7. Air Temperature for the Month of April 2016	12
Figure 8. Air Temperature for the Month of May 2016	13
Figure 9. Air Temperature for the Month of June 2016	13
Figure 10. Air Temperature for the Month of July 2016	14
Figure 11. Air Temperature for the Month of August 2016	14
Figure 12. Air Temperature for the Month of September 2016.....	15
Figure 13. Air Temperature for the Month of October 2016.....	15
Figure 14. Air Temperature for the Month of November 2016.....	16
Figure 15. Air Temperature for the Month of December 2016	16
Figure 16. Average Daily Barometric Pressure at Brookhaven National Laboratory for 2016.....	26
Figure 17. Barometric Pressure for the Month of January 2016.....	27
Figure 18. Barometric Pressure for the Month of February 2016.....	27
Figure 19. Barometric Pressure for the Month of March 2016.....	28
Figure 20. Barometric Pressure for the Month of April 2016.....	28
Figure 21. Barometric Pressure for the Month of May 2016.....	29
Figure 22. Barometric Pressure for the Month of June 2016.....	29
Figure 23. Barometric Pressure for the Month of July 2016	30
Figure 24. Barometric Pressure for the Month of August 2016	30
Figure 25. Barometric Pressure for the Month of September 2016	31
Figure 26. Barometric Pressure for the Month of October 2016	31
Figure 27. Barometric Pressure for the Month of November 2016	32
Figure 28. Barometric Pressure for the Month of December 2016.....	32
Figure 29. Daily Mean Relative Humidity at Brookhaven National Laboratory for 2016.....	33

Figure 30. Minimum Daily Humidity at Brookhaven National Laboratory for 2016	34
Figure 31. Maximum Daily Humidity at Brookhaven National Laboratory for 2016.....	34
Figure 32. Relative Humidity for the Month of January 2016	35
Figure 33. Relative Humidity for the Month of February 2016	35
Figure 34. Relative Humidity for the Month of March 2016	36
Figure 35. Relative Humidity for the Month of April 2016	36
Figure 36. Relative Humidity for the Month of May 2016.....	37
Figure 37. Relative Humidity for the Month of June 2016.....	37
Figure 38. Relative Humidity for the Month of July 2016	38
Figure 39. Relative Humidity for the Month of August 2016	38
Figure 40. Relative Humidity for the Month of September 2016.....	39
Figure 41. Relative Humidity for the Month of October 2016.....	39
Figure 42. Relative Humidity for the Month of November 2016	40
Figure 43. Relative Humidity for the Month of December 2016	40
Figure 44. Daily Rainfall Totals at Brookhaven National Laboratory for 2016.....	41
Figure 45. Daily Rainfall for the Month of January 2016	42
Figure 46. Daily Rainfall for the Month of February 2016	42
Figure 47. Daily Rainfall for the Month of March 2016	43
Figure 48. Daily Rainfall for the Month of April 2016	43
Figure 49. Daily Rainfall for the Month of May 2016	44
Figure 50. Daily Rainfall for the Month of June 2016	44
Figure 51. Daily Rainfall for the Month of July 2016	45
Figure 52. Daily Rainfall for the Month of August 2016	45
Figure 53. Daily Rainfall for the Month of September 2016.....	46
Figure 54. Daily Rainfall for the Month of October 2016.....	46
Figure 55. Daily Rainfall for the Month of November 2016	47
Figure 56. Daily Rainfall for the Month of December 2016	47
Figure 57. Average Daily Wind Speed (m/s) at the 10-meter, 50-meter and 85-meter heights at Brookhaven National Laboratory for 2016	52
Figure 58. Historic Annual One-hour Wind Roses for the Years 1994 to 2016 from the 85m level.....	53
Figure 59. Historic Annual One-hour Wind Roses for the Years 1994 to 2016 from the 10m level.....	53

Figure 60. Annual One-hour Wind Roses for the Year 2016 from the 85m level.....	54
Figure 61. Annual One-hour Wind Roses for the Year 2016 from the 50m level.....	54
Figure 62. Annual One-hour Wind Roses for the Year 2016 from the 10m level.....	55
Figure 63. One-hour Wind Roses for the Month of January 2016 from the 85m level.....	55
Figure 64. One-hour Wind Roses for the Month of January 2016 from the 10m level.....	56
Figure 65. One-hour Wind Roses for the Month of February 2016 from the 85m level.....	56
Figure 66. One-hour Wind Roses for the Month of February 2016 from the 10m level.....	57
Figure 67. One-hour Wind Roses for the Month of March 2016 from the 85m level.....	57
Figure 68. One-hour Wind Roses for the Month of March 2016 from the 10m level.....	58
Figure 69. One-hour Wind Roses for the Month of April 2016 from the 85m level.....	58
Figure 70. One-hour Wind Roses for the Month of April 2016 from the 50m level.....	59
Figure 71. One-hour Wind Roses for the Month of April 2016 from the 10m level.....	59
Figure 72. One-hour Wind Roses for the Month of May 2016 from the 85m level.....	60
Figure 73. One-hour Wind Roses for the Month of May 2016 from the 50m level.....	60
Figure 74. One-hour Wind Roses for the Month of May 2016 from the 10m level.....	61
Figure 75. One-hour Wind Roses for the Month of June 2016 from the 85m level.....	61
Figure 76. One-hour Wind Roses for the Month of June 2016 from the 50m level.....	62
Figure 77. One-hour Wind Roses for the Month of June 2016 from the 10m level.....	62
Figure 78. One-hour Wind Roses for the Month of July 2016 from the 85m level.....	63
Figure 79. One-hour Wind Roses for the Month of July 2016 from the 50m level.....	63
Figure 80. One-hour Wind Roses for the Month of July 2016 from the 10m level.....	64
Figure 81. One-hour Wind Roses for the Month of August 2016 from the 85m level.....	64
Figure 82. One-hour Wind Roses for the Month of August 2016 from the 50m level.....	65
Figure 83. One-hour Wind Roses for the Month of August 2016 from the 10m level.....	65
Figure 84. One-hour Wind Roses for the Month of September 2016 from the 85m level	66
Figure 85. One-hour Wind Roses for the Month of September 2016 from the 50m level (station out of service 9-1 thru 9-20)	66
Figure 86. One-hour Wind Roses for the Month of September 2016 from the 10m level	67
Figure 87. One-hour Wind Roses for the Month of October 2016 from the 85m level	67
Figure 88. One-hour Wind Roses for the Month of October 2016 from the 50m level	68
Figure 89. One-hour Wind Roses for the Month of October 2016 from the 10m level	68
Figure 90. One-hour Wind Roses for the Month of November 2016 from the 85m level	69
Figure 91. One-hour Wind Roses for the Month of November 2016 from the 50m level	69

Figure 92. One-hour Wind Roses for the Month of November 2016 from the 10m level	70
Figure 93. One-hour Wind Roses for the Month of December 2016 from the 85m level.....	70
Figure 94. One-hour Wind Roses for the Month of December 2016 from the 50m level.....	71
Figure 95. One-hour Wind Roses for the Month of December 2016 from the 10m level.....	71
Figure 96. Wind Speed for the Month of January 2016	72
Figure 97. Wind Gust data for the Month of January 2016	72
Figure 98. Wind Speed for the Month of February 2016	73
Figure 99. Wind Gust data for the Month of February 2016	73
Figure 100. Wind Speed for the Month of March 2016	74
Figure 101. Wind Gust data for the Month of March 2016	74
Figure 102. Wind Speed for the Month of April 2016	75
Figure 103. Wind Gust data for the Month of April 2016	75
Figure 104. Wind Speed for the Month of May 2016.....	76
Figure 105. Wind Gust data for the Month of May 2016	76
Figure 106. Wind Speed for the Month of June 2016.....	77
Figure 107. Wind Gust data for the Month of June 2016	77
Figure 108. Wind Speed for the Month of July 2016	78
Figure 109. Wind Gust data for the Month of July 2016	78
Figure 110. Wind Speed for the Month of August 2016	79
Figure 111. Wind Gust data for the Month of August 2016	79
Figure 112. Wind Speed for the Month of September 2016.....	80
Figure 113. Wind Gust data for the Month of September 2016	80
Figure 114. Wind Speed for the Month of October 2016.....	81
Figure 115. Wind Gust data for the Month of October 2016.....	81
Figure 116. Wind Speed for the Month of November 2016	82
Figure 117. Wind Gust data for the Month of November 2016.....	82
Figure 118. Wind Speed for the Month of December 2016	83
Figure 119. Wind Gust data for the Month of December 2016	83
Figure 120. Daily Peak Solar Irradiance at Brookhaven National Laboratory for 2016	86
Figure 121. Average Daily Solar Irradiance at Brookhaven National Laboratory for 2016	86
Figure 122. Global Horizontal Irradiance – 2016 Monthly Daily-Average	87
Figure 123. Average Daily Diffuse Solar Irradiance at Brookhaven National Laboratory for 2016	87

Figure 124. Average Daily Direct Normal Solar Irradiance at Brookhaven National Laboratory for 2016.....	88
Figure 125. Average Daily Long-wave Far Infrared Irradiance at Brookhaven National Laboratory for 2016	88
Figure 126. Global Solar Radiation for the Month of January 2016	91
Figure 127. Global Solar Radiation for the Month of February 2016	91
Figure 128. Global Solar Radiation for the Month of March 2016	92
Figure 129. Global Solar Radiation for the Month of April 2016	92
Figure 130. Global Solar Radiation for the Month of May 2016	93
Figure 131. Global Solar Radiation for the Month of June 2016	93
Figure 132. Global Solar Radiation for the Month of July 2016.....	94
Figure 133. Global Solar Radiation for the Month of August 2016	94
Figure 134. Global Solar Radiation for the Month of September 2016.....	95
Figure 135. Global Solar Radiation for the Month of October 2016.....	95
Figure 136. Global Solar Radiation for the Month of November 2016.....	96
Figure 137. Global Solar Radiation for the Month of December 2016	96
Figure 138. Diffuse Solar Radiation for the Month of January 2016	97
Figure 139. Diffuse Solar Radiation for the Month of February 2016	97
Figure 140. Diffuse Solar Radiation for the Month of March 2016	98
Figure 141. Diffuse Solar Radiation for the Month of April 2016	98
Figure 142. Diffuse Solar Radiation for the Month of May 2016	99
Figure 143. Diffuse Solar Radiation for the Month of June 2016	99
Figure 144. Diffuse Solar Radiation for the Month of July 2016.....	100
Figure 145. Diffuse Solar Radiation for the Month of August 2016	100
Figure 146. Diffuse Solar Radiation for the Month of September 2016	101
Figure 147. Diffuse Solar Radiation for the Month of October 2016.....	101
Figure 148. Diffuse Solar Radiation for the Month of November 2016.....	102
Figure 149. Diffuse Solar Radiation for the Month of December 2016	102
Figure 150. Direct Solar Radiation for the Month of January 2016	103
Figure 151. Direct Solar Radiation for the Month of February 2016	103
Figure 152. Direct Solar Radiation for the Month of March 2016	104
Figure 153. Direct Solar Radiation for the Month April 2016	104
Figure 154. Direct Solar Radiation for the Month May 2016.....	105

Figure 155. Direct Solar Radiation for the Month June 2016.....	105
Figure 156. Direct Solar Radiation for the Month July 2016	106
Figure 157. Direct Solar Radiation for the Month August 2016	106
Figure 158. Direct Solar Radiation for the Month September 2016.....	107
Figure 159. Direct Solar Radiation for the Month October 2016	107
Figure 160. Direct Solar Radiation for the Month November 2016.....	108
Figure 161. Direct Solar Radiation for the Month December 2016	108
Figure 162. Long-wave Far Infrared Radiation for the Month of January 2016	109
Figure 163. Long-wave Far Infrared Radiation for the Month of February 2016	109
Figure 164. Long-wave Far Infrared Radiation for the Month of March 2016	110
Figure 165. Long-wave Far Infrared Radiation for the Month of April 2016	110
Figure 166. Long-wave Far Infrared Radiation for the Month of May 2016	111
Figure 167. Long-wave Far Infrared Radiation for the Month of June 2016	111
Figure 168. Long-wave Far Infrared Radiation for the Month of July 2016	112
Figure 169. Long-wave Far Infrared Radiation for the Month of August 2016	112
Figure 170. Long-wave Far Infrared Radiation for the Month of September 2016	113
Figure 171. Long-wave Far Infrared Radiation for the Month of October 2016.....	113
Figure 172. Long-wave Far Infrared Radiation for the Month of November 2016.....	114
Figure 173. Long-wave Far Infrared Radiation for the Month of December 2016	114
Figure 174. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of January 2016	115
Figure 175. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of February 2016	115
Figure 176. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of March 2016	116
Figure 177. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of April 2016	116
Figure 178. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of May 2016	117
Figure 179. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of June 2016	117
Figure 180. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of July 2016	118

Figure 181. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of August 2016.....	118
Figure 182. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of September 2016	119
Figure 183. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of October 2016.....	119
Figure 184. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of November 2016.....	120
Figure 185. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of December 2016.....	120
Figure 186. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for January 2016	121
Figure 187. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for January 2016	121
Figure 188. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for February 2016	122
Figure 189. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for February 2016	122
Figure 190. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for March 2016	123
Figure 191. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for March 2016	123
Figure 192. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for April 2016	124
Figure 193. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for April 2016	124
Figure 194. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for May 2016	125
Figure 195. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for May 2016	125
Figure 196. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for June 2016	126

Figure 197. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for June 2016	126
Figure 198. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for July 2016.....	127
Figure 199. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for July 2016	127
Figure 200. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for August 2016.....	128
Figure 201. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for August 2016.....	128
Figure 202. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for September 2016	129
Figure 203. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for September 2016	129
Figure 204. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for October 2016.....	130
Figure 205. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for October 2016.....	130
Figure 206. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for November 2016.....	131
Figure 207. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for November 2016.....	131
Figure 208. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for December 2016	132
Figure 209. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for December 2016	132

Purpose

This document presents the meteorological data collected at Brookhaven National Laboratory (BNL) by Meteorological Services (Met Services) for the calendar year 2016. The purpose is to publicize the data sets available to emergency personnel, researchers and facility operations. Met services has been collecting data at BNL since 1949. Data from 1994 to the present is available in digital format. Data is presented in monthly plots of one-minute data. This allows the reader the ability to peruse the data for trends or anomalies that may be of interest to them. Full data sets are available to BNL personnel and to a limited degree outside researchers. The full data sets allow plotting the data on expanded time scales to obtain greater details (e.g., daily solar variability, inversions, etc.).

Background

Meteorological Services (Met Services) is responsible for the maintenance, calibration, data collection and data archiving for the weather instrumentation network at Brookhaven National Laboratory. Measurements include wind speed, wind direction, temperature, rainfall, barometric pressure and relative humidity. Wind speed, wind direction and temperature are measured at 85 meters, 50 meters and at 10 meters. Rainfall, relative humidity, temperature and barometric pressure are taken at the 2 meter height. This critical data set is used for NEPA calculations, for emergency planning and operations (i.e., chemical spill or accidental release) and general research. In addition to the weather sensors, Met Services maintains a solar resource base station which measures solar radiation at BNL. Instruments include Solys-2, sun tracker equipped with a pyrheliometer (direct normal incidence radiation), a ventilated, shaded pyrgeometer (downwards long-wave, infrared radiation), a ventilated, shaded, research grade pyranometer (diffuse solar radiation) and a ventilated, unshaded, research grade pyranometer (global solar radiation). The base station also has a Sky Imager for cloud imaging and SP-Lite2 pyranometers (in-plane and horizontal) that replicate the research array sensors at the Long Island Solar Farm (LISF) and the Northeast Solar Energy Research Center (NSERC).

Meteorological data is also presented in real time via a webserver at <http://wx1.bnl.gov>. Current weather parameters are posted here. Using buttons and pull-down menus the user has a method to graph the data from several hours to several days for the past 12 months (<http://wx1.bnl.gov/graph.html>) and to see information on stability class (<http://wx1.bnl.gov/stability.php>). Graphing includes barometric pressure, temperature, wind speed, wind direction, wind gust, humidity, precipitation and solar radiation. To facilitate safe climbing of the 85-meter met tower, we also maintain a webpage with a graphical presentation of wind speed and wind gust for the past four hours (<http://wx1.bnl.gov/towerclimb.html>). This page allows workers to see the wind conditions on the tower and thereby, determine if the winds are within BNL's safe parameters (25 mph or less at the time of a climb). The page reports data from both sets of sensors on the tower, giving redundancy and a better safety margin. In addition, Met Services has a QA/QC webpage that shows all sensors over the past 24 hours (<http://wx1.bnl.gov/graphpage.html>). This allows us to periodically (daily or greater) check the sensors and see that they are within reasonable limits and agreement.

Site

Weather conditions at the BNL site have been recorded since August 1948. BNL is broadly influenced by continental and maritime weather systems. Locally, the major weather systems are modified by the Long Island Sound, the Atlantic Ocean and associated bays, which influence wind directions and humidity, and provide a moderating influence on extreme summer and winter temperatures.

BNL is a well-ventilated site, with an annual distribution of wind direction reflecting a predominance of westerly components. Prevailing winds are from the south-southwest during the summer, from the west-northwest during the winter, and about equally from these two directions during the spring and fall.

Instrument Towers

85-meter Tower

The 85-meter (280-ft.) meteorological tower was placed in operation in May 1981 to replace the former and original "Ace Tower" used in the first 30 operational years at BNL. The tower (Fig. 1) is located in an open field west of the majority of the Brookhaven building complex at latitude $40^{\circ}52'14.84''N$ and longitude $72^{\circ}53'20.05''W$ and its base is 24 m (80 ft.) above sea level and is referred to as "Tower Ten". In this document, the primary, tall tower will be called, the main or 85-meter tower to avoid confusion with the smaller, secondary 10-meter tower also in operation at the Met field.

The main tower is made of galvanized steel, is triangular in shape with 3 ft. sides and has 3 sets of 8 guy wires to keep it upright. It has an inside ladder for climbing, and two working levels with small platforms. It is difficult to mount booms and equipment or to work on this tower. Special safety belts and harnesses are required when climbing, maintaining or calibrating equipment on this tower. Sensor location names designate the approximate height of the sensors above the ground. At each location there are fully redundant sensor sets. Each set is independent of the other with unique data loggers and sensors. At locations M85 and M50 instrumentation includes; R.M. Young model 5106 Marine grade wind monitors for wind speed and direction and R.M. Young model 41342VC temperature probes. The temperature probes are protected by naturally aspirated radiation shields. Data collection is via Campbell CR1000 data loggers and transmitted to the main data computer via Campbell model RF401, 900-MHz Spread-Spectrum Radio modems.

10-meter Tower

A foldable-mast, ten-meter tower is located approximately at the center of the Meteorological field. Again, fully redundant sensor sets are present. Instrumentation includes R.M. Young model 5106 Marine grade wind monitors for wind speed and direction and R.M. Young model 41342VC temperature probes. The temperature probes are protected by naturally aspirated radiation shields. Data collection is via Campbell CR1000 data loggers and transmitted to the main data computer via Campbell model RF401, 900-MHz Spread-Spectrum Radio modems.

2-meter pole

At two meters (located near the 10-meter tower) sensors include; Campbell/Rotonic HC2-S3 temperature and relative humidity probes and R.M. Young model 61302V barometric pressure sensors. The T/RH probes have actively aspirated (powered fan) shields. Data collection is via Campbell CR1000 data loggers and transmitted to the main data computer via Campbell model RF401, 900-MHz Spread-Spectrum Radio modems.

Two tipping-bucket rain gauges (Novalynx model 260-2501) are maintained on the roof of building 490D. This location was chosen for available 115VAC for the heaters in the gauges required for winter use. Data collection is via Campbell CR1000 data loggers with direct network connections.

Solar Base Station

Met Services maintains a platform on the roof of building 490D. This platform is used for testing of sensors and also houses the LISF research projects base station for solar irradiance measurements. Instrumentation at this location includes; a Kipp and Zonen model Solys-2 suntracker equipped with a shaded Kipp and Zonen model CGR-4 pyrgeometer for long-wave, far infrared radiation, a Kipp and Zonen model CHP-1 pyrheliometer to measure direct normal incident radiation and two Kipp and Zonen CMP-22 research grade pyranometers, one shaded and one unshaded, to record diffuse and global radiation. BNL is also home to the Long Island Solar Farm (LISF) and the Northeast Solar Energy Research Center (NSERC) where we maintain an array of sensors, including pyranometers. As a reference for the LISF sensor array, two Kipp and Zonen model SP-lite2 pyranometers are maintained, one in-plane (aka tilted global radiation) at the 27° angle of inclination for the panels at the LISF and one horizontal (global radiation). Similarly, for the NSERC sensor array, two SP-lite2 pyranometers are maintained, one in-plane at the 23° angle of inclination for the panels at the NSERC and a mating horizontally aligned unit. Data collection is via a Campbell CR3000 data loggers directly connected to the network. Additionally, a sky imaging camera is mounted on the platform and is directly connected to the network. Images from the camera are available to BNL users.

Calibrations

All sensors are calibrated annually in accordance to the BNL Meteorological Instrument Network Calibration Plan (Heiser 2012). Where an instrument is sent off site for calibration a duplicate calibrated unit is available for replacement.

The calibration and maintenance frequency is based on the following hierarchy:

1. Manufacturers recommendation as stated in the instruments Operation Manual or Owner's Instruction Manual.
2. Manufacturers recommendation as stated in other communications such as a memorandum, email, or documented phone conversation.

3. Other engineering or scientific standards specifically referring to a particular type of instrument (e.g., American Nuclear Society, American National Standards Institute).
4. Met Services determination of calibration needs based on experience with the equipment and/or recommendations from other sources.

Calibration certificates are required from the companies performing calibrations and these certificates are compiled in the Instrument Calibration Notebooks. For sensors that are calibrated on site or in-situ by BNL personnel, the data taken is recorded on instrument specific data sheets and the sheets are compiled into the Instrument Calibration Notebooks. The original notebooks are maintained by the head of Met Services. Additionally, an electronic master list of equipment and the current status of each instruments calibration along with calibration coefficients is maintained on the Met Services master computer with copies available from the Head of Met Services and the Operations Officer.

Data Sets and Data Availability

Meteorological sensors are checked daily and duplicate sensors inter-compared. On a monthly basis the data goes through a QA/QC process to help eliminate bad records and correct or remove any erroneous values. The post processing of the data involves visually analyzing the data in eight day increments looking for bad data points. IGOR Pro, data analysis software, is used for this purpose. Using a series of scripts it is relatively easy to remove single or multiple data points. Once the bad data is removed the operator can chose to fill in the missing points by interpolation or leave the data as “missing”. The data is then saved to a file. This data is then backed up along with the raw unedited data. In addition to this we also do a comparative analysis on the “A” and “B” datasets to insure precision between the two independent systems. Data reported is generally taken from the “A” side sensors with “B” side sensors serving as backups. If data checks show the A sensors to be out of service, out of spec or questionable the data is replaced by B sensor data until the A sensor is replaced/repaired.

After the editing is complete, daily and hourly averages and sums are calculated and saved to files to be disseminated upon request. The averages are then added to a spreadsheet that includes all the past data collected here at BNL, going back as far as 1949. See;
<http://www.bnl.gov/weather/MonthlyClimatology.asp>

Currently data is available as monthly, daily, hourly and one minute averages. Subsets of the main data set are also available. Most requests are for a small, specific time frame, which can usually be produced in one to two days.

Meteorological Data Recovery for 2016

For the year, Met Services had a 100 percent record retrieval rate, collecting all of the 527,040 records. This equates to a total of 10,540,800 fields of data that could have been collected for the year. During the course of the year there was one significant failure. Instrumentation at the 50-meter level on the main tower was damaged during restoration work and did not collect data during the period from January 15th at 1221 until March 23rd at 1226. In addition to this major

outage there were a number of smaller events that amounted to usually less than one hour of data loss. Of the 10,540,800 data points available for collection the system failed to record 643,742 data points. This equates to 93.89% data recovery for the year.

For the Solar Base Station system there were no significant failures in 2016. There were a few short time losses that totaled 688 missing data points out of a possible 4,216,320 for the year which represents a 99.98% data recovery rate for the year.

Tables 1a and 1b list the current year meteorological extremes and totals as well as historic extremes for BNL.

2016 Meteorological Data

Table 1a. 2016 Extremes and Totals^a

Highest Temperature	35.6 C° August 14 th
Lowest Temperature	-21.0 C° February 15 th
Average Yearly Temperature	11.5 C°
Annual Precipitation	38.93"
Maximum Monthly Precipitation	5.40" in February
Minimum Monthly Precipitation	1.17" in June
Maximum Daily Precipitation	1.80" on November 29 th
Maximum Hourly Rainfall	0.98" on August 20 th from 0900hrs to 1000hrs
Maximum Wind Speed (85 meters)	23.4 m/s (47.9 mph) January 23 rd
Maximum Wind Gust (85 meters)	32.3 m/s (60.6 mph) February 25 th
Maximum Wind Speed (10 meters)	12.8 m/s (23.5 mph) February 16 th
Maximum Wind Gust (10 meters)	26.5 m/s (42.7 mph) June 11 th
Maximum Barometric Pressure	1038.7 mbar December 26 th
Lowest Barometric Pressure	985.7 mbar April 3 rd
Lowest Relative Humidity	11% April 20 th
Heating Degree Days	5411.4
Cooling Degree Days	817.2
Average Daily Irradiance	170 W/m ²

a = Measurements taken at the 2 meter height unless otherwise noted.

Table 1b. Historic Extremes^a

Highest Temperature	38.1 C (100.5 F) July 21 1991 & July 22, 1957
Lowest Temperature	-31.1 C (-23 F) January 22, 1961
Average Yearly Temperature	10.3 C (50.5 F)
Coldest Year	1967 (Avg. Temp. = 8.6 C / 47.5 F)
Warmest Year	2012 (Avg. Temp. = 12.3 C / 54.3 F)
Greatest Daily Temperature Range	31.4 C (56.5 F)
Least Daily Temperature Range	0.3 C / 0.5 F
Maximum Annual Degree Days	6753 for 1967
Maximum Monthly Degree Days	1414 in January 1977
Average Annual Precipitation	48.93"
Maximum Annual Precipitation	68.66" in 1989
Minimum Annual Precipitation	34.35" in 1965
Maximum Monthly Precipitation	22.14" in October 2005
Minimum Monthly Precipitation	Trace in June 1949, 0.18" October 1963 9.02" September 10 - 11, 1954 Hurricane Edna
Maximum Daily Precipitation	9.00" October 14th, 2005
Maximum Hourly Rainfall	2.10" September 10 - 11, 1954 Hurricane Edna
Maximum Seasonal Snowfall	90.8" 1995-96
Minimum Seasonal Snowfall	4.5" 1997-98
Maximum Monthly Snowfall	35.8 February 2013
Maximum Daily Snowfall	19.0" February 1978
Maximum Snowfall, Single Storm	30.9" February 8-9, 2013
Longest Period Snow Cover	55 days (Dec. 26, 1947 - February 18, 1948)
Earliest Snowfall	October 17
Latest Snowfall	April 27
Peak Wind Speed	125 mph - August 31, 1954 Hurricane Carol
Lowest Barometric Pressure	28.375" September 12, 1960 Hurricane Donna

a = Measurements taken at the 2 meter height unless otherwise noted

Air Temperature

Temperature is measured using platinum resistance thermometers (PRT) at 2-meters (Campbell HC2-S3), 10-meters (R.M. Young 41342VC), 50-meters (R.M. Young 41342VC) and 85-meters (R.M. Young 41342VC) at the locations described above.

All probes are calibrated internally by BNL staff. A high quality constant temperature bath along with a reference PRT are used to perform a comparison calibration curve. The PRT is calibrated off-site to NIST standards. Met Services uses the comparison method of calibrating temperature sensors. The thermometer is calibrated by comparison with a reference or standard thermometer in a thermally stabilized bath. The procedure uses a four point calibration consisting of -10°C, 5°C, 20°C and 35°C. ANSI/ANS-3.11-2005 lists the air temperature minimum accuracy of 0.5°C and a minimum resolution of 0.1°C. For stability class determinations using vertical temperature differences the requirements are; a minimum accuracy of 0.1°C and a minimum resolution of 0.01°C. Meteorological data is held to the later, more stringent requirement

For platinum resistance probes and modest accuracy applications the resistance-temperature relationship can be approximated by the Callendar-Van Dusen equation as:

$$R(t) = R(0)[1 + At + Bt^2 + C(t-100)t^3]$$

Where:

t = temperature (°C),

R(t) = resistance at temperature t,

R(0) = resistance at 0°C,

and using ASTM 1137 and IEC 60751 coefficient values for a standard 100 ohm sensor having an alpha value of 0.00385;

A = 3.9083 x 10-3 (°C-1),

B = -5.775 x 10-7 (°C-2) and

C = -4.183 x 10-12 (°C-4) [for temperatures above 0°C, C = 0]

Within the temperature range of BNLs minimum observed temperature (-31°C) and maximum observed temperature (38°C), the B and C coefficients can be ignored and approximated as zero and;

$$R(t) = R(0) + R(0) \cdot At$$

Daily average temperature for the year is presented in Figure 1. Daily minimums and maximums for the year are shown in Figure 2. Table 2 summarizes the 2 meter monthly average daily temperatures, average daily minimum and maximum temperatures and monthly extreme high and lows. Figure 3 depicts the monthly temperature means and compares them to historic means. Table 3, 4 and 5 lists the historic monthly average, average monthly maximum and average monthly minimum temperatures from 1949 to present. Monthly data plots of 1-minute data at the four met field measurement locations are presented in Figures 4 through 15.

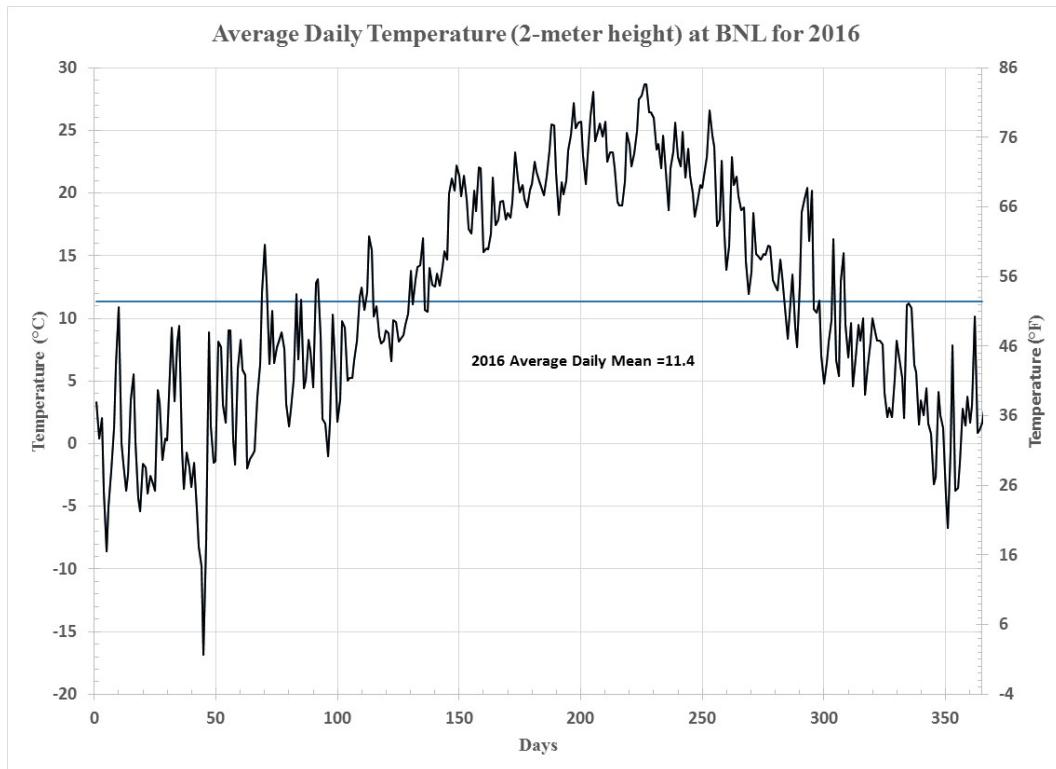


Figure 1 Average Daily Temperature taken at the 2 meter height at BNL for 2016

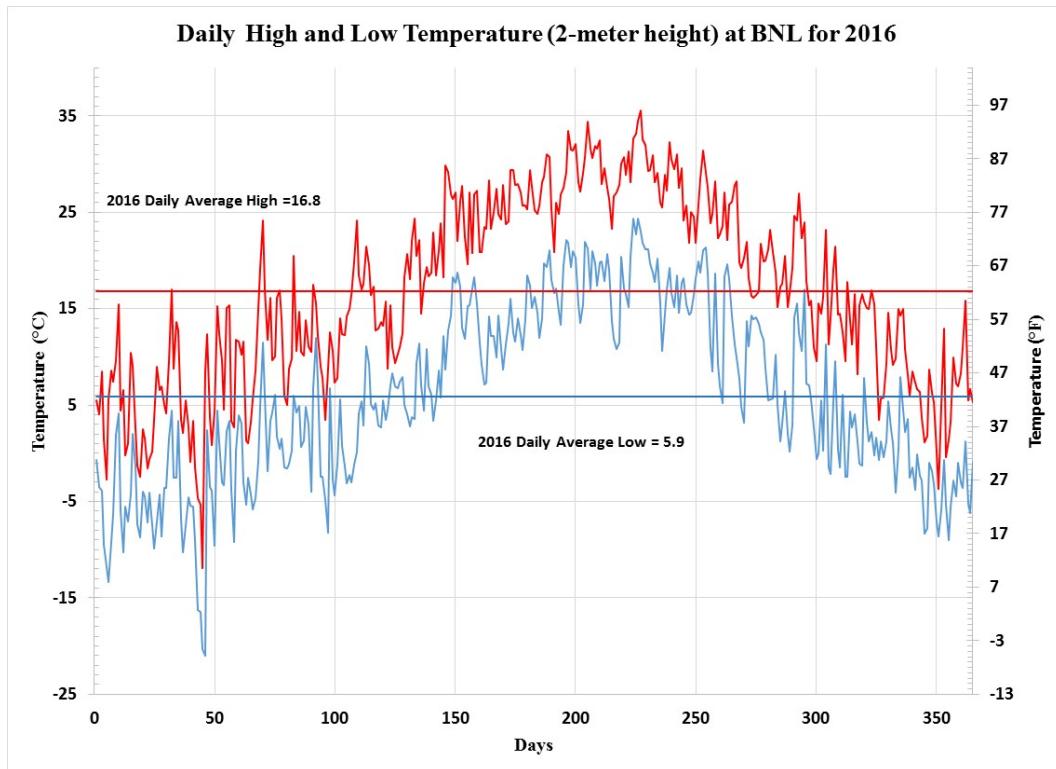


Figure 2 Daily Minimums and Maximums in Temperature taken at the 2 meter height at BNL for 2016

Table 2. Monthly Temperature Summary

Month	2016 Temperatures (°C) @ 2 meters						
	Average			Extremes			
	Daily Mean	Daily High	Daily Low	High	Date	Low	Date
Jan	-0.3	4.5	-5.3	15.5	Jan 10 th	-13.4	Jan 6 th
Feb	1.0	6.1	-4.8	17.0	Feb 1 st	-21.0	Feb 15 th
Mar	6.4	11.6	1.2	24.2	Mar 10 th	-5.8	Mar 6 th
Apr	8.0	14.0	1.9	24.2	Apr 18 th	-8.2	Apr 6 th
May	13.9	19.5	8.6	29.9	May 25 th	2.8	May 10 th
Jun	19.2	25.5	13.0	29.4	Jun 21 st	7.1	Jun 10 th
Jul	23.4	28.9	18.1	34.4	Jul 23 rd	12.0	Jul 3 rd
Aug	23.6	29.5	17.8	35.6	Aug 14 th	10.6	Aug 23 rd
Sep	19.0	24.0	13.9	31.4	Sep 9 th	3.2	Sep 26 th
Oct	12.5	18.5	7.0	27	Oct 19 th	-1.5	Oct 31 st
Nov	7.4	13.1	1.8	21.5	Nov 3 rd	-4.1	Nov 28 th
Dec	1.8	6.4	-3.1	15.8	Dec 27 th	-9.0	Dec 20 th

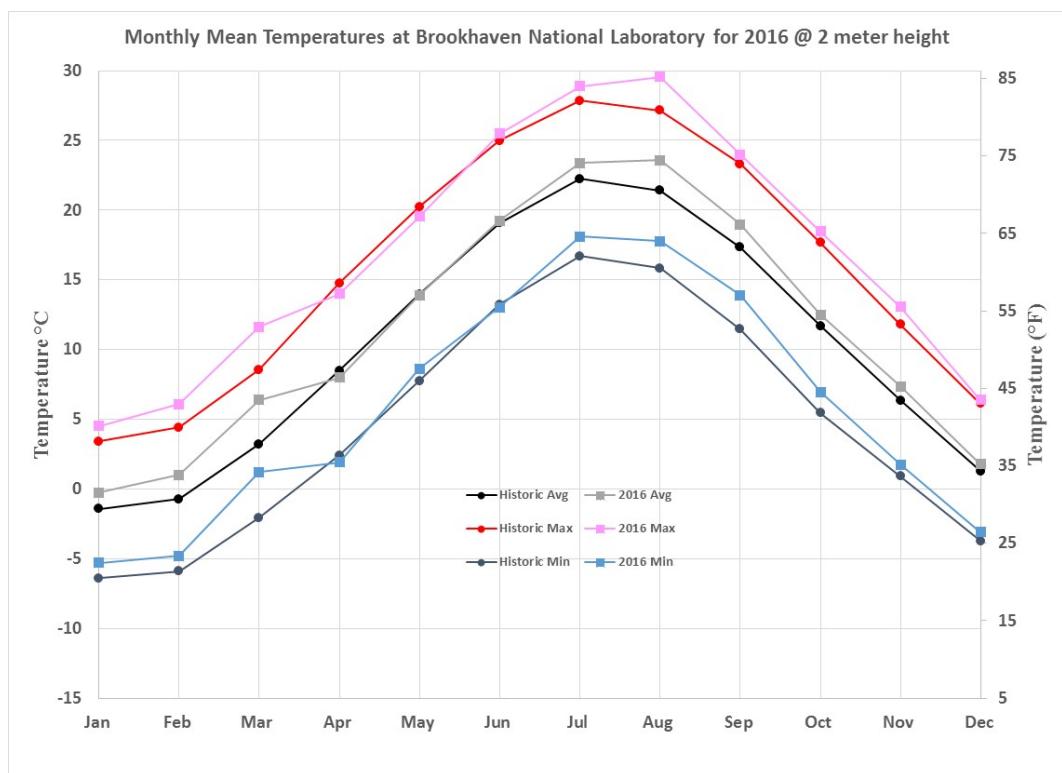


Figure 3 Monthly Mean Temperatures (°C) at Brookhaven National Laboratory for 2016

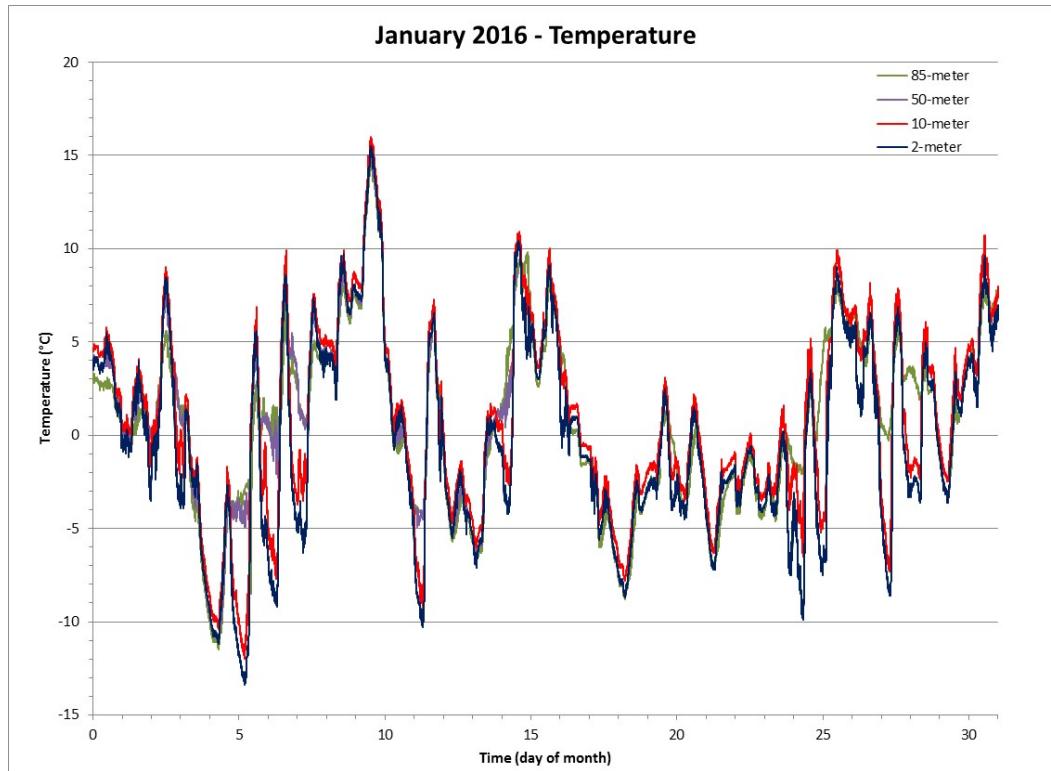


Figure 4 Air Temperature for the Month of January 2016

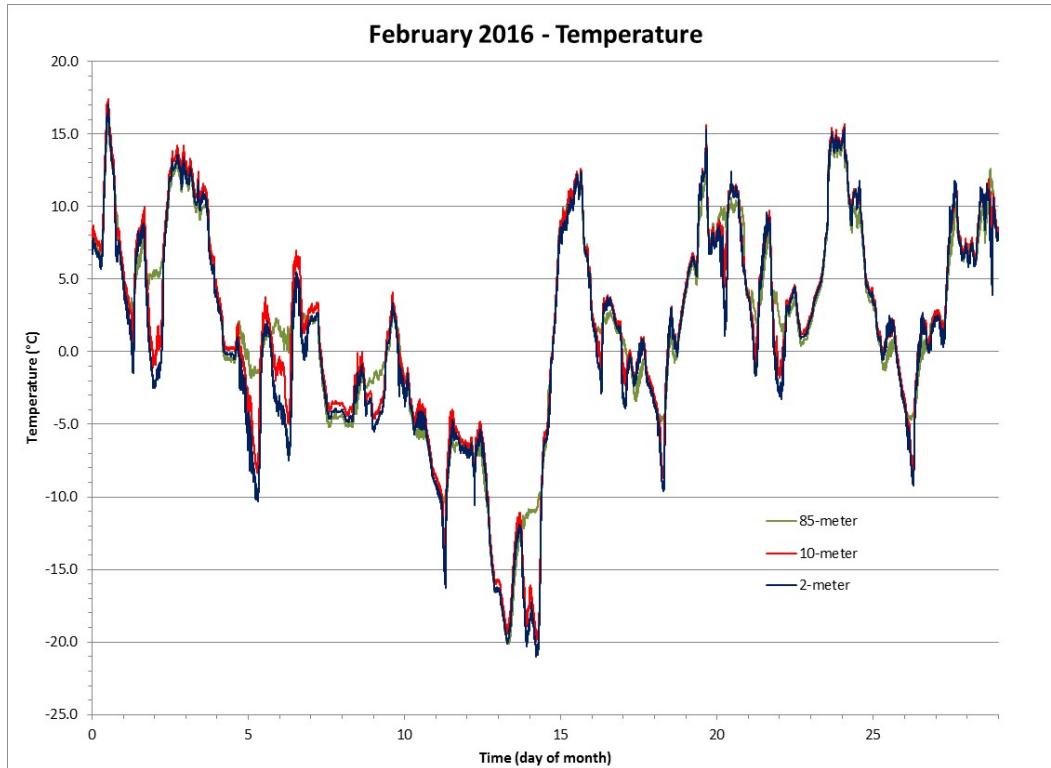


Figure 5 Air Temperature for the Month of February 2016

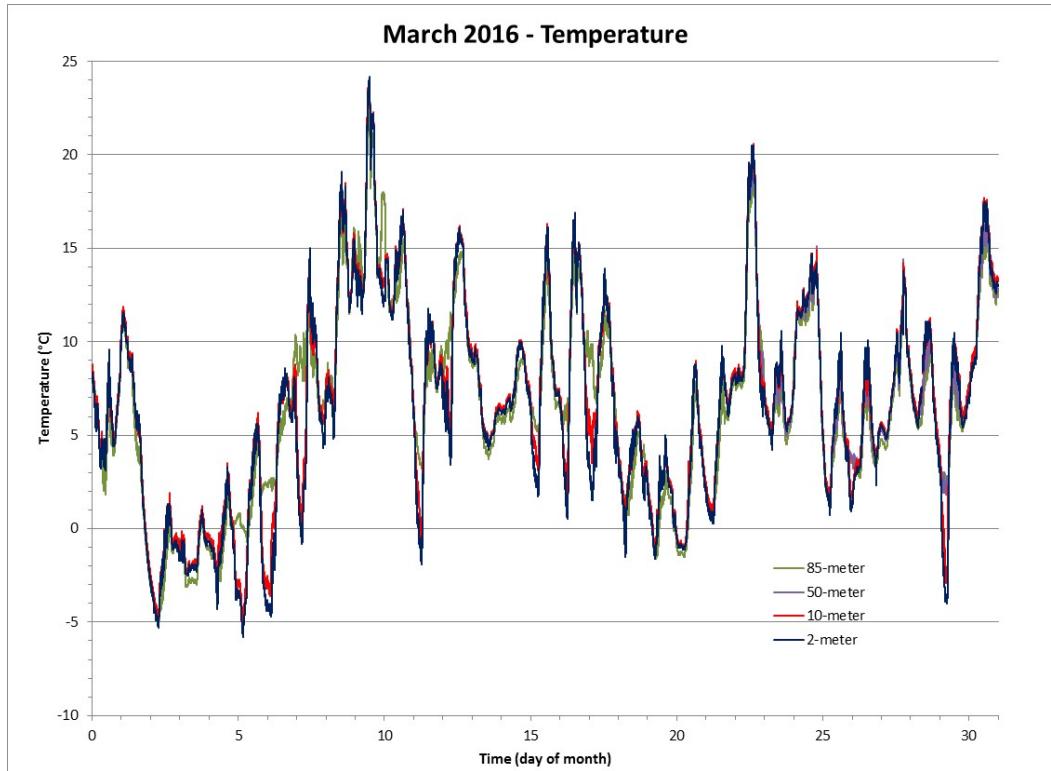


Figure 6 Air Temperature for the Month of March 2016

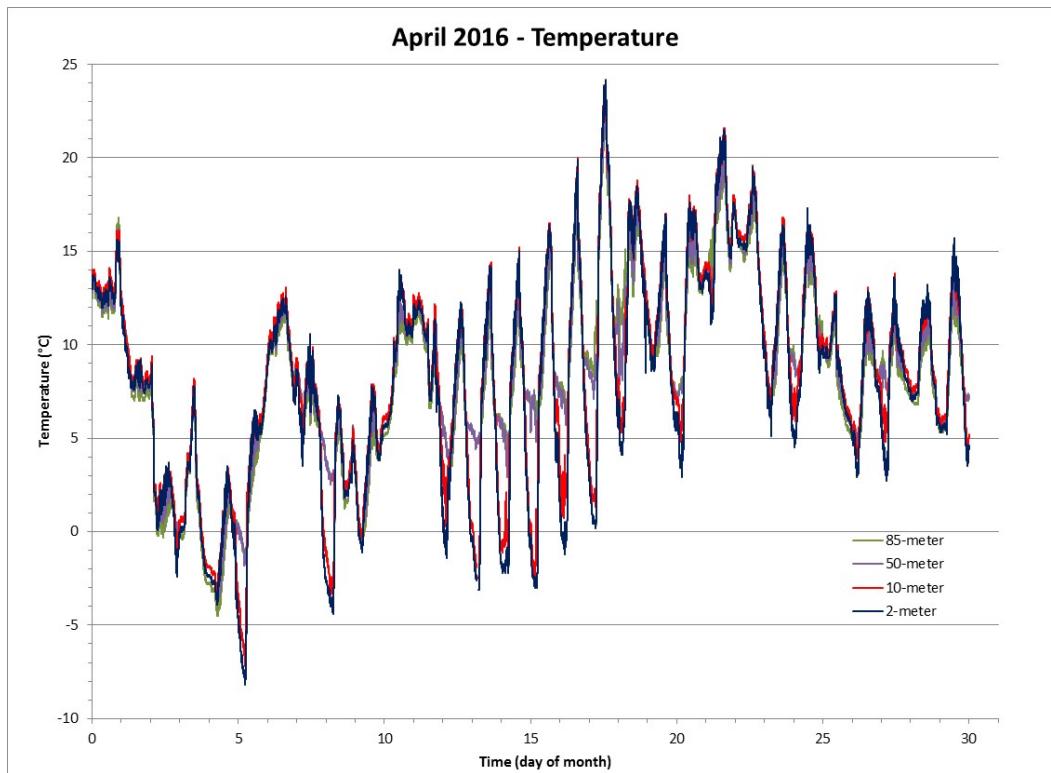


Figure 7 Air Temperature for the Month of April 2016

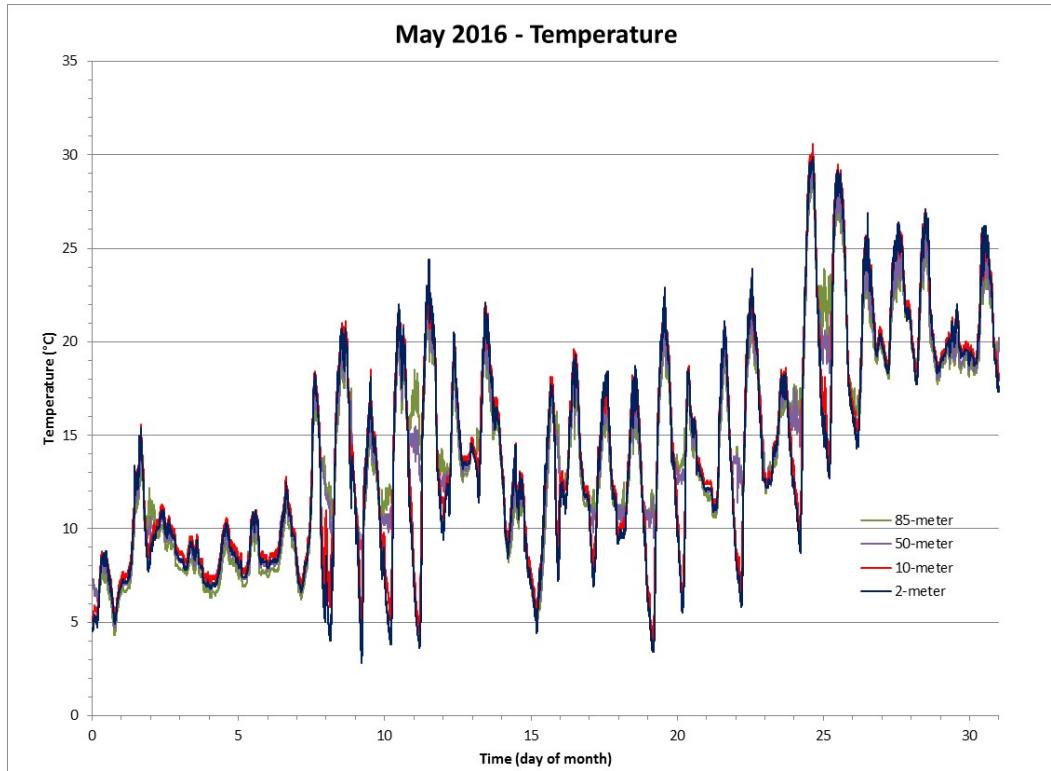


Figure 8 Air Temperature for the Month of May 2016

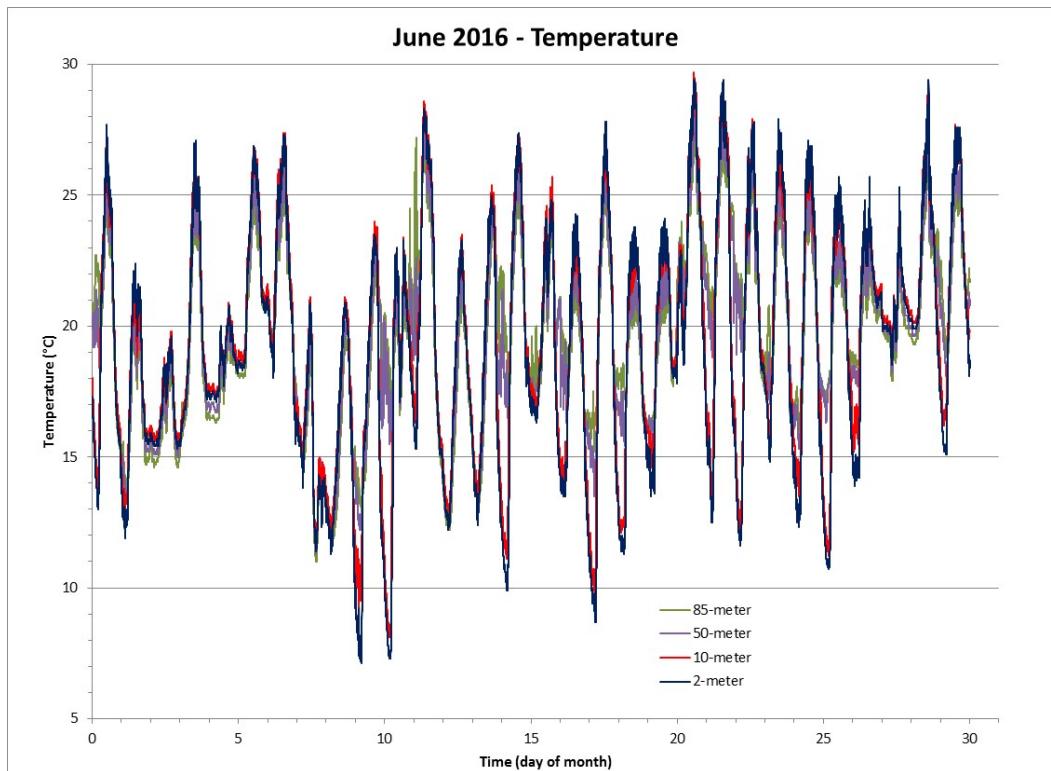


Figure 9 Air Temperature for the Month of June 2016

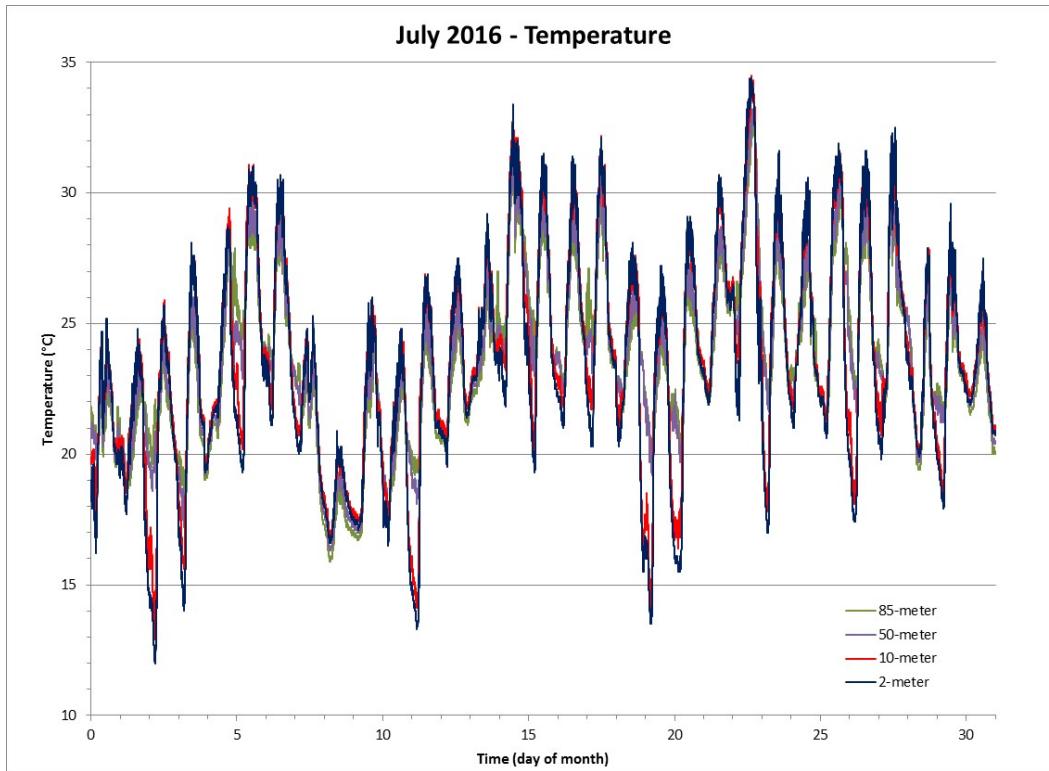


Figure 10 Air Temperature for the Month of July 2016

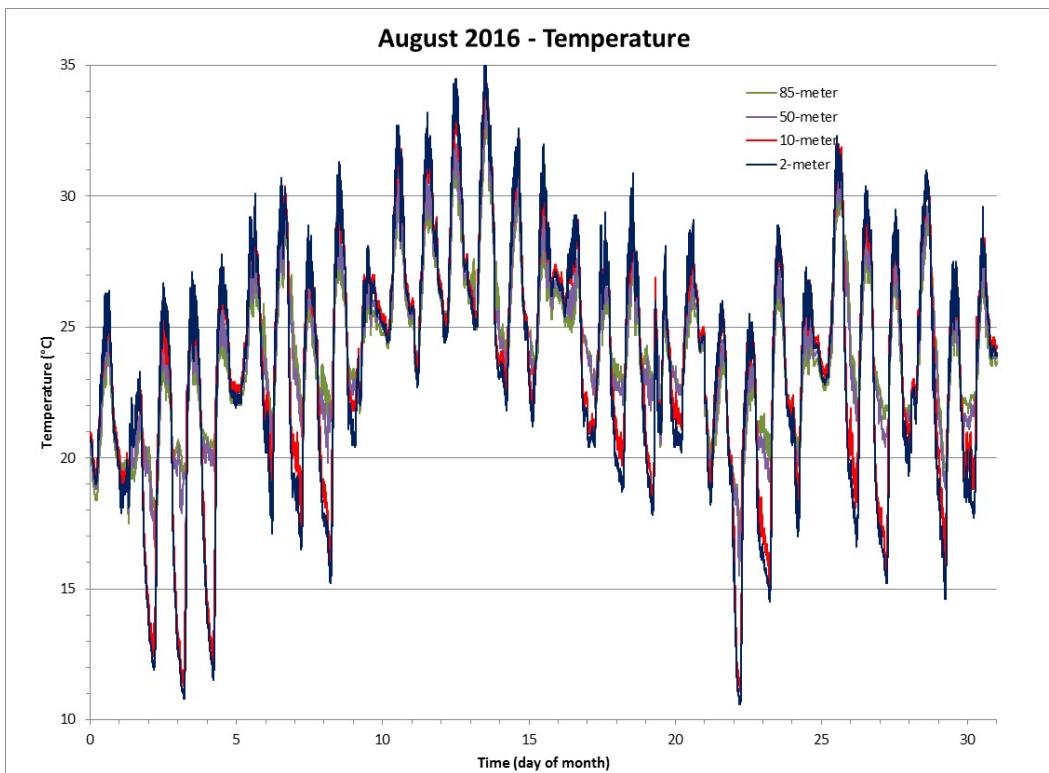


Figure 11 Air Temperature for the Month of August 2016

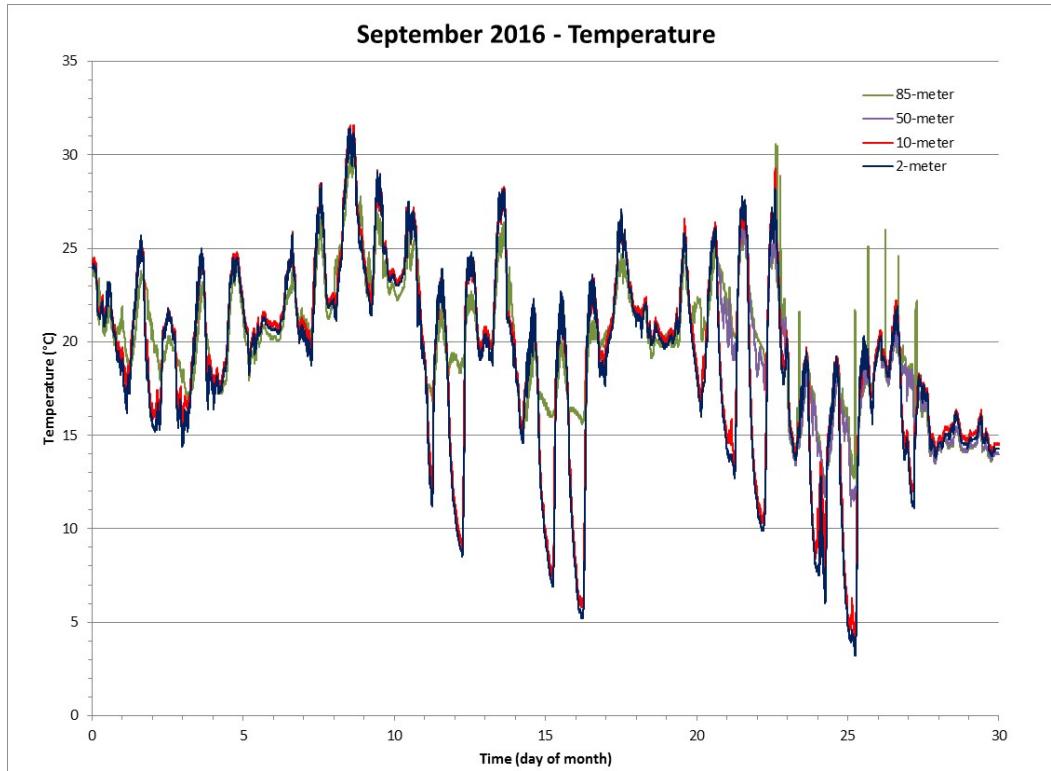


Figure 12 Air Temperature for the Month of September 2016

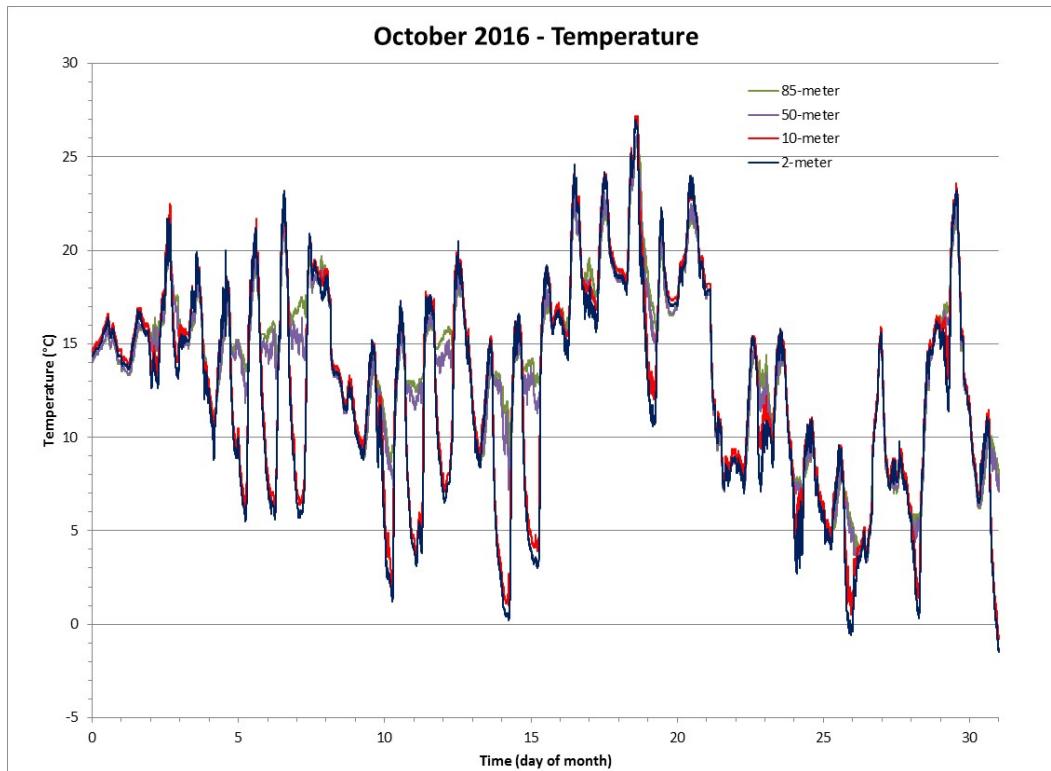


Figure 13 Air Temperature for the Month of October 2016

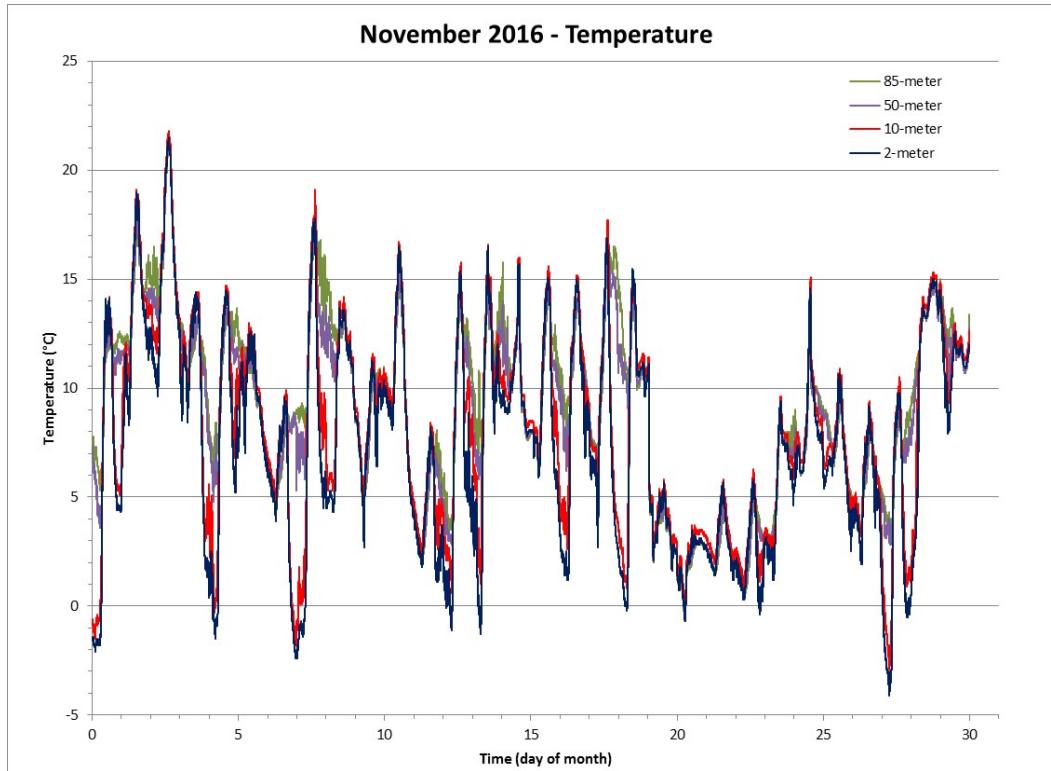


Figure 14 Air Temperature for the Month of November 2016

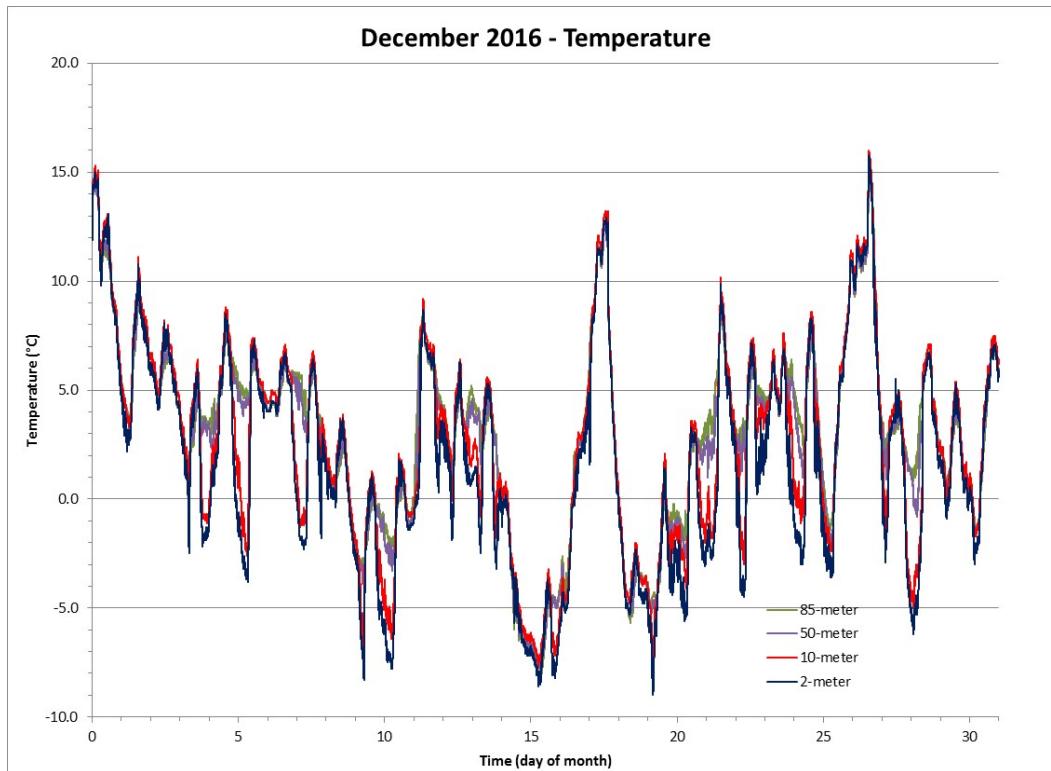


Figure 15 Air Temperature for the Month of December 2016

**Table 3. Historic Monthly Mean Temperatures (°C) for Brookhaven National Laboratory from 1949 to present
(@ 2 meters)**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1949	2.3	2.0	3.6	9.5	14.3	20.1	23.3	21.9	16.2	14.1	5.6	1.2	11.2
1950	3.3	-1.7	0.6	6.3	11.9	17.9	21.1	19.7	15.4	12.1	6.3	0.0	9.4
1951	0.1	-0.1	3.2	8.6	13.9	17.6	21.5	20.3	16.9	11.9	4.4	7.2	10.5
1952	0.2	-0.1	2.7	9.2	12.8	19.8	23.5	21.2	16.7	9.8	5.9	1.6	10.3
1953	1.2	1.6	3.8	8.4	14.6	18.3	21.5	20.2	17.4	18.3	6.2	3.1	11.2
1954	-3.1	1.4	2.8	8.6	11.9	18.9	20.8	19.4	16.1	13.1	4.7	0.0	9.6
1955	-2.4	-1.1	3.1	9.2	14.7	17.3	23.8	22.1	15.8	12.4	4.5	-4.1	9.6
1956	-2.2	0.3	0.7	5.6	11.4	18.4	20.3	20.4	15.2	15.0	5.4	2.3	9.4
1957	-4.6	0.5	3.4	9.0	13.7	20.7	21.9	19.2	17.4	10.9	7.4	2.7	10.2
1958	-1.2	-3.6	2.8	8.3	11.7	16.3	22.3	20.4	16.2	10.1	5.8	-4.3	8.7
1959	-2.4	-2.4	2.1	8.4	14.6	17.8	21.3	22.1	18.3	12.2	5.9	1.6	10.0
1960	-0.8	1.2	-0.6	8.6	14.2	18.9	20.4	20.5	15.6	10.1	6.8	-2.6	9.4
1961	-4.8	-1.4	2.5	7.1	12.3	18.9	21.6	21.3	20.6	12.5	6.1	0.3	9.7
1962	-1.2	-1.2	2.9	7.6	13.3	18.6	19.3	19.4	14.8	10.3	4.0	-2.2	8.8
1963	-2.2	-3.4	4.1	8.4	12.9	19.1	21.1	19.6	15.2	13.2	8.0	-2.9	9.4
1964	-1.0	-2.6	3.0	6.6	15.1	18.1	21.8	18.8	16.4	10.4	6.0	1.7	9.5
1965	-3.6	-1.6	2.1	6.6	15.3	18.2	20.3	20.3	17.1	10.5	4.8	1.2	9.3
1966	-2.3	-1.1	3.2	5.8	11.6	18.9	22.4	21.1	16.0	9.2	6.3	-0.4	9.2
1967	0.5	-4.1	0.1	6.8	10.1	18.5	21.6	20.6	15.4	9.9	3.5	0.4	8.6
1968	-4.3	-4.0	3.1	8.2	11.8	17.8	21.9	20.6	17.8	10.1	5.8	-1.2	9.0
1969	-2.3	-1.3	1.1	8.4	13.1	17.6	20.2	22.0	16.8	10.7	4.9	-0.7	9.2
1970	-5.7	-2.0	1.4	7.9	14.2	19.1	22.4	21.9	18.1	11.6	6.8	0.2	9.6
1971	-4.4	-0.7	2.8	5.9	12.2	18.6	20.7	20.3	18.9	14.4	5.0	2.8	9.7
1972	-0.4	-1.9	2.2	6.1	13.8	18.1	22.7	20.6	18.2	8.5	4.0	1.9	9.5

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1973	-0.3	-0.8	6.1	9.6	13.0	20.8	22.4	22.2	16.7	11.3	6.6	2.2	10.8
1974	0.0	-2.5	4.1	9.7	12.9	18.4	22.2	22.1	17.1	8.8	6.3	1.6	10.1
1975	1.2	-0.8	1.7	6.6	15.4	19.2	22.9	19.1	16.1	12.3	8.5	0.8	10.2
1976	-4.6	1.6	3.6	9.8	13.1	20.1	21.1	21.2	16.4	9.7	3.2	-3.1	9.3
1977	-6.9	-1.4	5.6	8.3	14.9	18.1	22.3	22.0	18.4	10.3	6.6	0.0	9.8
1978	-3.3	-5.4	1.4	7.8	14.1	17.7	20.0	21.8	14.5	9.5	5.9	1.4	8.8
1979	-1.5	-6.5	5.4	7.4	15.2	17.1	22.6	21.9	16.8	11.5	8.4	3.3	10.1
1980	-1.2	-3.1	1.7	8.5	15.1	17.8	22.8	21.6	18.7	11.5	4.7	-1.7	9.7
1981	-6.9	0.3	2.6	9.3	14.6	20.2	23.6	21.6	17.1	9.7	6.5	0.5	9.9
1982	-5.2	-0.5	2.2	7.2	14.8	17.2	22.2	20.1	16.5	11.1	7.6	4.0	9.8
1983	0.0	-0.9	5.0	8.7	12.4	19.3	23.0	21.9	18.6	11.8	7.2	-0.3	10.6
1984	-4.0	2.8	0.7	8.4	12.8	20.1	21.4	22.1	15.6	13.0	6.1	3.9	10.2
1985	-4.2	-0.4	4.7	10.0	14.8	17.3	21.9	20.7	17.9	11.7	8.2	-0.9	10.1
1986	-1.1	-2.1	3.8	8.6	15.1	18.4	21.8	19.9	16.2	11.6	5.2	1.9	9.9
1987	-1.5	-1.5	4.4	9.7	14.4	20.2	22.9	20.2	17.2	9.6	6.7	1.5	10.3
1988	-4.2	-0.7	3.2	7.8	14.3	18.8	23.3	23.0	16.1	8.9	6.5	-0.2	9.7
1989	0.4	-1.1	3.2	7.7	14.3	20.3	21.9	21.8	17.7	11.9	5.6	-4.5	9.9
1990	2.9	1.8	4.4	8.7	13.2	19.3	22.5	22.3	17.0	14.2	7.6	4.1	11.5
1991	-0.6	1.9	5.4	10.6	16.9	20.3	22.7	22.7	16.8	12.6	7.1	2.6	11.6
1992	-0.5	0.4	2.3	7.2	13.2	18.2	20.6	20.1	17.3	10.2	5.9	1.6	9.7
1993	0.7	-2.9	1.9	9.1	15.3	19.8	23.3	22.1	17.7	10.4	5.8	1.2	10.4
1994	-4.1	-2.5	3.1	9.9	13.5	21.1	24.9	20.6	17.2	11.4	9.1	3.7	10.7
1995	2.6	-1.3	4.9	8.1	13.4	19.4	23.6	22.2	17.0	13.6	5.1	-1.1	10.6
1996	-1.6	-0.4	1.4	8.6	13.7	19.6	21.1	21.4	18.0	11.2	4.3	3.6	10.1
1997	-1.1	2.5	3.2	8.3	12.6	18.6	22.3	21.2	17.1	11.1	5.2	1.9	10.2
1998	3.3	2.9	4.8	9.2	15.6	18.7	22.4	22.4	18.7	12.2	6.7	3.4	11.7

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	0.1	1.3	4.1	9.1	14.8	20.7	24.6	22.1	18.7	11.1	8.6	3.1	11.5
2000	-1.8	1.1	6.1	8.2	15.1	19.6	20.6	21.4	17.3	11.8	6.0	-1.6	10.3
2001	-1.4	0.2	2.6	9.6	15.2	21.1	20.7	23.5	17.6	12.3	9.0	4.7	11.3
2002	3.0	2.3	5.4	10.8	13.8	19.3	23.4	23.3	18.7	11.5	6.2	0.6	11.5
2003	-3.2	-2.2	3.6	8.0	12.9	18.8	22.7	23.7	18.8	11.2	8.5	2.3	10.4
2004	-4.7	0.3	4.4	9.7	16.2	19.4	22.1	21.6	19.0	11.9	7.1	1.6	10.7
2005	-1.8	0.1	1.7	9.5	12.3	20.8	23.4	24.6	20.2	13.2	8.3	0.7	11.1
2006	3.0	0.2	3.8	9.9	14.9	20.2	23.8	22.4	17.1	11.7	9.2	4.9	11.8
2007	2.1	-2.2	3.4	7.9	15.3	19.6	22.4	22.2	18.7	16.1	5.8	1.3	11.1
2008	1.0	1.3	2.7	10.1	13.3	21.3	23.6	21.6	17.7	11.1	5.8	3.7	11.1
2009	-3.3	1.1	3.4	10.1	14.6	17.8	21.1	22.8	16.9	11.4	9.3	1.3	10.6
2010	-1.3	-0.3	6.8	10.7	16.2	21.3	24.6	22.7	19.7	12.8	7.1	-0.4	11.7
2011	-2.7	0.3	4.0	9.9	15.8	20.2	24.1	22.3	19.6	12.7	9.4	4.7	11.7
2012	2.2	3.2	8.0	10.7	16.4	19.6	23.3	22.7	18.3	14.0	5.2	4.4	12.3
2013	0.9	0.2	3.2	9.2	14.4	20.1	24.4	21.1	17.1	13.3	5.9	2.1	11.0
2014	-2.7	-1.8	1.3	8.3	14.8	19.3	22.0	20.3	18.0	13.3	5.6	3.3	10.1
2015	-2.6	-6.9	0.7	8.7	16.0	19.1	23.1	23.1	20.2	11.4	8.6	8.1	10.8
2016	-0.3	1.0	6.4	8.0	13.9	19.2	23.4	23.6	19.0	12.5	7.4	1.8	11.3
Average	-1.4	-0.7	3.2	8.5	14.0	19.1	22.2	21.4	17.3	11.7	6.4	1.3	10.3
Max	3.3	3.2	8.0	10.8	16.9	21.3	24.9	24.6	20.6	18.3	9.4	8.1	12.3
Min	-6.9	-6.9	-0.6	5.6	10.1	16.3	19.3	18.8	14.5	8.5	3.2	-4.5	8.6

Min Max

Table 4. Historic Monthly Mean Maximum Temperatures (°F) for Brookhaven National Laboratory from 1949 to present (@ 2 meters)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1949	6.6	7.1	8.4	15.0	20.4	26.0	28.7	27.9	21.7	19.9	11.5	6.9	16.7
1950	8.3	3.1	6.3	12.0	17.9	24.4	27.1	25.3	21.1	18.9	12.8	5.3	15.2
1951	5.8	6.1	8.3	15.8	21.4	23.6	27.5	26.2	23.8	17.7	10.4	7.3	16.2
1952	5.4	4.9	7.1	15.4	19.5	26.3	30.5	27.2	29.1	16.8	12.0	6.3	16.7
1953	6.2	7.0	8.7	24.1	20.2	26.1	28.6	27.0	24.7	18.8	13.4	8.6	17.8
1954	2.6	7.7	8.9	15.2	18.4	25.2	27.8	25.8	22.1	19.5	10.5	4.5	15.7
1955	1.7	4.2	8.2	14.9	22.4	23.9	29.6	27.9	22.1	18.4	9.8	1.0	15.3
1956	1.9	4.9	5.8	12.2	18.1	25.7	25.4	26.5	21.1	17.7	11.3	7.6	14.9
1957	0.4	5.6	9.2	15.5	20.6	27.2	28.6	25.8	23.4	16.9	13.0	7.9	16.2
1958	3.1	0.7	7.1	14.5	17.3	22.3	27.3	25.9	22.1	15.8	11.6	1.3	14.1
1959	2.8	3.1	7.1	14.5	21.3	23.5	26.2	27.4	24.6	17.7	11.2	6.6	15.5
1960	3.4	6.1	4.1	15.2	20.7	25.2	26.6	26.1	21.3	17.4	13.2	3.7	15.3
1961	1.1	4.7	7.7	12.4	18.3	25.1	27.1	26.7	25.9	18.7	11.3	4.7	15.3
1962	3.8	2.8	8.8	14.1	20.6	24.7	25.9	25.3	21.1	16.9	9.6	3.3	14.7
1963	3.2	2.2	9.0	15.5	20.1	25.8	27.4	25.6	20.6	20.6	12.9	1.6	15.3
1964	4.4	2.6	8.2	12.2	22.7	24.3	26.2	25.5	22.8	17.3	13.2	6.0	15.4
1965	1.5	3.2	6.9	12.8	22.6	24.8	26.6	26.0	22.4	16.3	10.6	6.5	15.0
1966	2.2	4.1	8.6	12.1	17.7	25.3	29.3	27.6	21.9	17.1	12.6	4.9	15.3
1967	5.7	2.1	5.7	12.8	16.3	24.8	26.6	25.2	22.2	17.0	8.9	6.2	14.4
1968	0.7	1.9	9.2	16.6	18.8	23.2	28.0	26.8	25.0	18.6	10.4	3.6	15.2
1969	2.1	2.2	6.3	14.6	19.9	23.8	24.9	27.6	22.9	17.5	10.3	3.6	14.7
1970	-0.7	3.9	6.3	14.1	19.9	24.4	27.4	28.1	24.1	18.1	11.9	4.5	15.2
1971	0.4	4.1	7.4	12.6	18.3	25.4	26.7	26.9	23.8	20.6	10.0	7.8	15.3
1972	5.3	3.6	7.2	12.4	20.4	22.9	27.8	26.9	24.3	15.2	8.2	5.4	14.9
1973	5.0	3.6	11.1	15.1	18.1	25.9	28.1	28.9	23.6	18.6	11.6	7.7	16.4

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1974	5.0	2.8	9.4	15.7	18.9	23.9	28.4	28.5	22.4	15.7	12.3	6.7	15.8
1975	5.9	4.2	7.4	12.7	21.9	24.4	28.1	27.3	21.6	18.4	14.3	5.8	16.0
1976	1.1	8.2	9.1	17.1	19.2	25.9	26.7	26.9	22.9	14.7	8.6	2.5	15.3
1977	-1.9	3.5	11.1	14.8	22.3	23.8	28.6	27.6	23.2	15.9	11.2	4.5	15.4
1978	1.5	0.2	6.9	13.6	19.1	24.4	25.6	26.6	21.2	16.1	11.2	6.6	14.4
1979	2.8	-2.6	10.6	13.2	20.2	22.8	28.2	26.4	22.8	16.5	13.4	7.4	15.2
1980	3.5	1.6	6.3	14.0	21.7	24.1	27.6	28.6	24.9	16.7	9.6	3.7	15.2
1981	-1.5	5.6	8.1	14.7	20.8	25.7	29.2	26.9	22.0	15.1	11.1	4.6	15.2
1982	-0.1	3.6	7.7	13.8	20.8	22.0	28.2	25.8	22.7	18.2	13.1	9.0	15.4
1983	4.8	5.7	9.7	14.3	18.0	26.7	29.6	27.8	25.6	17.4	12.7	4.8	16.4
1984	1.2	7.5	5.7	13.9	18.8	26.2	26.4	27.8	22.4	18.7	11.8	9.8	15.8
1985	0.9	4.6	10.9	16.2	21.4	23.5	28.0	26.6	24.6	18.6	12.8	4.0	16.0
1986	4.6	2.3	10.3	15.0	22.3	24.6	27.2	25.4	21.7	17.7	10.8	6.3	15.7
1987	3.3	3.6	10.7	15.4	21.0	26.1	28.6	26.2	22.8	17.1	12.7	6.5	16.2
1988	1.6	4.5	9.3	13.1	20.2	25.7	28.6	28.6	22.8	15.0	12.9	5.4	15.7
1989	6.0	3.7	8.2	14.1	20.1	25.7	27.2	27.1	23.8	18.6	10.8	0.4	15.5
1990	7.3	7.4	10.4	13.9	18.9	25.1	27.2	27.1	23.1	19.9	13.8	9.1	16.9
1991	4.9	7.5	10.3	16.4	23.7	26.7	28.8	28.2	22.7	18.4	11.9	7.9	17.3
1992	5.0	5.7	7.7	12.9	20.1	23.9	26.2	25.5	22.3	16.4	10.8	6.4	15.2
1993	5.2	3.1	6.8	14.4	22.2	25.7	29.6	27.9	22.6	16.2	12.5	6.1	16.0
1994	1.1	2.6	8.3	16.5	20.1	26.7	29.9	26.2	23.0	18.1	14.4	9.1	16.3
1995	6.6	4.2	10.4	14.3	19.3	25.1	28.5	29.1	23.4	20.2	10.1	4.2	16.3
1996	3.1	4.4	7.3	14.1	19.8	24.6	25.3	26.3	22.8	17.4	9.5	7.8	15.2
1997	3.8	7.4	8.7	14.4	18.7	25.3	28.4	26.9	23.2	17.8	10.0	6.9	15.9
1998	7.7	7.8	9.7	15.2	21.7	23.7	28.1	28.3	24.7	17.8	12.3	9.2	17.2
1999	5.6	6.6	9.7	15.9	21.7	26.8	30.7	27.1	23.9	17.7	14.1	8.1	17.3
2000	3.2	6.2	12.2	13.5	21.1	25.0	25.8	26.3	23.1	18.0	11.1	3.2	15.7
2001	3.9	5.6	7.2	15.8	21.3	26.8	26.6	27.5	23.9	18.9	15.2	10.0	16.9

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2002	7.7	8.7	10.8	16.9	19.9	25.3	29.4	28.9	24.4	16.6	10.9	5.6	17.1
2003	0.8	2.3	10.2	13.3	18.4	23.8	27.7	28.1	23.7	16.8	13.7	7.2	15.5
2004	-0.7	5.6	8.8	14.9	21.8	25.1	27.0	26.4	24.7	16.9	12.6	7.0	15.8
2005	2.7	5.6	7.3	16.5	18.0	25.9	28.5	30.0	27.3	17.6	13.7	5.4	16.6
2006	7.8	5.7	9.3	16.8	20.3	24.7	28.7	27.7	22.5	17.4	14.1	10.1	17.1
2007	6.1	2.0	9.2	13.7	22.3	25.3	27.6	27.4	24.9	21.1	11.1	5.7	16.4
2008	5.4	6.3	8.4	16.4	19.4	27.0	28.9	27.6	22.7	17.0	10.4	8.3	16.5
2009	1.0	6.1	8.9	15.8	19.8	22.9	26.3	28.1	22.4	16.6	13.2	5.3	15.6
2010	2.6	3.2	12.1	18.3	22.4	26.7	30.4	27.8	24.6	17.8	11.7	2.9	16.7
2011	0.9	5.4	8.9	14.9	21.3	25.7	29.6	27.3	24.3	17.8	14.8	9.7	16.7
2012	7.0	7.9	13.2	16.8	21.3	25.0	28.7	28.0	23.4	18.2	10.1	8.5	17.3
2013	4.9	3.7	7.4	15.1	20.6	25.3	29.0	26.6	23.3	19.3	11.4	6.7	16.1
2014	2.6	3.9	7.6	14.8	20.8	25.3	27.1	26.4	23.3	17.7	10.4	6.9	15.6
2015	1.4	-1.6	5.8	14.4	22.1	24.2	28.1	29.0	26.8	16.9	14.0	12.5	16.1
2016	4.5	6.1	11.6	14.0	19.5	25.5	28.9	29.5	24.0	18.5	13.1	6.4	16.8
Average	3.4	4.4	8.5	14.8	20.2	25.0	27.8	27.1	23.3	17.7	11.8	6.1	15.9
Max	8.3	8.7	13.2	24.1	23.7	27.2	30.7	30.0	29.1	21.1	15.2	12.5	17.8
Min	-1.9	-2.6	4.1	12.0	16.3	22.0	24.9	25.2	20.6	14.7	8.2	0.4	14.1

Min

Max

Table 5. Historic Monthly Mean Minimum Temperatures (°F) for Brookhaven National Laboratory from 1949 to present (@2 meters)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1949	-1.7	-3.1	-0.8	4.3	7.9	14.1	17.9	15.8	10.7	8.3	-0.4	-4.4	5.7
1950	-1.7	-6.6	-5.1	0.7	5.9	11.4	15.2	13.9	10.0	5.0	0.0	-4.2	3.7
1951	-5.6	-5.0	-2.5	1.4	6.7	12.2	15.8	14.4	9.9	5.9	-1.3	-4.2	4.0
1952	-5.0	-5.1	-2.1	3.4	6.8	13.2	16.4	15.4	9.2	2.7	0.1	-3.2	4.3
1953	-3.3	-3.8	-1.1	2.9	9.1	11.6	14.3	13.0	10.1	4.1	-1.2	-2.6	4.4
1954	-8.1	-4.1	-3.1	1.9	5.0	12.6	13.9	13.2	10.4	6.3	-1.4	-4.6	3.5
1955	-6.7	-6.4	-2.5	3.5	7.0	10.7	18.1	16.2	9.8	6.4	-0.6	-9.2	3.9
1956	-6.3	-4.2	-4.6	-1.1	4.8	10.9	15.1	14.3	9.2	3.1	-0.3	-2.9	3.2
1957	-9.7	-4.7	-2.2	2.6	6.8	14.3	15.3	12.6	11.4	4.8	1.8	-2.3	4.2
1958	-5.5	-7.8	-1.2	2.1	6.1	10.3	17.3	14.7	10.4	4.3	0.1	-9.9	3.4
1959	-7.6	-7.7	-2.9	2.3	7.8	12.2	16.5	16.8	12.1	6.7	0.6	-3.6	4.4
1960	-5.1	-3.1	-5.1	2.0	7.5	12.6	14.4	15.0	9.9	2.8	0.4	-8.7	3.6
1961	-10.7	-7.0	-2.7	1.8	6.7	12.4	16.1	15.8	15.2	6.4	0.8	-4.7	4.2
1962	-7.5	-6.7	-2.6	1.2	6.1	12.3	12.3	13.4	8.6	3.9	-1.5	-7.6	2.7
1963	-7.7	-9.0	-1.1	1.4	5.9	12.4	15.2	13.6	9.9	5.9	3.2	-6.8	3.6
1964	-6.4	-7.9	-2.2	0.9	7.6	12.1	17.4	12.2	10.1	3.6	-1.1	-2.6	3.7
1965	-8.9	-6.1	-2.8	0.3	8.1	11.6	13.9	14.5	11.8	4.4	-0.9	-4.0	3.5
1966	-6.8	-6.4	-2.4	-0.4	5.5	12.6	15.6	14.6	10.2	1.4	0.4	-5.7	3.2
1967	-4.5	-10.0	-5.5	0.8	4.1	12.3	17.4	16.2	8.9	3.1	-1.8	-5.4	2.9
1968	-9.1	-9.8	-2.8	-0.1	5.3	12.6	15.8	14.4	10.6	6.9	1.1	-6.1	3.3
1969	-6.7	-4.9	-4.1	2.2	6.2	11.4	15.6	16.1	10.7	4.5	-0.4	-4.9	3.8
1970	-10.7	-7.9	-3.6	1.9	8.4	13.6	17.3	15.6	12.1	5.4	1.7	-4.1	4.1
1971	-9.5	-5.4	-1.9	-0.7	6.1	12.2	14.8	13.6	14.2	8.6	0.0	-2.1	4.2

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1972	-6.2	-7.5	-2.6	-0.3	6.9	13.2	17.7	13.9	12.0	1.8	-0.2	-1.6	3.9
1973	-6.0	-5.2	0.9	4.1	7.9	15.8	16.7	17.5	10.0	3.9	1.6	-2.2	5.4
1974	-5.0	-7.9	-1.3	3.7	6.9	13.2	16.0	15.4	11.9	2.1	0.2	-3.5	4.3
1975	-3.4	-5.9	-4.0	0.5	9.1	13.9	17.8	16.1	10.5	6.3	3.2	-4.8	4.9
1976	-10.4	-5.3	-1.8	2.6	6.9	14.2	15.4	15.4	9.8	4.7	-2.3	-8.6	3.4
1977	-12.2	-6.5	0.0	0.9	7.4	12.3	16.1	16.5	13.6	4.7	1.9	-4.5	4.2
1978	-8.1	-11.5	-3.9	1.9	8.9	11.0	14.4	17.0	7.7	2.9	0.5	-3.9	3.1
1979	-5.8	-10.5	-0.3	1.6	10.2	11.4	16.9	17.4	10.8	6.4	3.3	-1.0	5.1
1980	-5.8	-7.7	-2.9	2.9	8.6	11.6	18.0	17.9	12.3	6.3	-0.3	-6.9	4.5
1981	-12.3	-4.9	-3.4	4.0	8.3	14.7	18.0	15.9	12.2	4.3	2.0	-3.6	4.6
1982	-10.4	-4.6	-3.4	0.7	8.7	12.3	16.3	14.4	10.3	4.1	2.1	-1.0	4.1
1983	-4.8	-5.5	0.3	3.1	6.8	11.9	16.4	16.1	11.7	6.1	1.7	-5.3	4.9
1984	-9.3	-1.8	-4.2	2.9	6.9	13.9	16.3	16.4	8.8	7.3	0.2	-1.9	4.6
1985	-9.3	-5.4	-1.4	3.8	8.2	11.1	15.8	14.8	11.2	4.8	3.6	-5.8	4.3
1986	-6.7	-6.6	-2.7	2.1	7.8	12.2	16.4	14.5	10.8	5.4	-0.6	-2.5	4.2
1987	-6.3	-6.6	-1.9	3.9	7.8	14.4	17.2	14.1	11.5	2.2	0.7	-3.6	4.4
1988	-10.0	-5.9	-3.1	2.5	8.3	12.0	17.9	17.4	9.4	2.8	0.1	-5.8	3.8
1989	-5.2	-5.9	-2.4	1.3	8.6	14.9	16.6	16.7	11.6	5.3	0.3	-9.4	4.3
1990	-1.4	-3.8	-1.6	3.5	7.4	13.6	17.8	17.4	10.9	8.3	1.4	-0.9	6.1
1991	-6.0	-3.6	0.6	4.7	10.1	13.9	16.7	17.2	10.8	6.8	2.2	-2.6	5.9
1992	-5.9	-4.7	-3.1	1.7	6.2	12.5	15.1	14.7	12.4	3.9	1.1	-3.3	4.2
1993	-3.8	-8.9	-2.9	3.6	8.5	13.8	16.9	16.2	12.8	4.7	-1.1	-3.7	4.7
1994	-9.1	-7.7	-2.2	3.4	6.9	15.4	20.0	14.9	11.4	4.7	3.7	-1.7	5.0
1995	-1.6	-6.9	-0.6	1.8	7.5	13.8	18.7	15.3	10.7	6.9	0.2	-5.9	5.0
1996	-6.2	-5.3	-4.6	3.2	7.6	14.7	16.8	16.6	13.2	4.9	-0.9	-0.7	4.9
1997	-5.8	-2.4	-2.3	2.2	6.6	11.9	16.1	15.6	11.1	4.4	0.3	-3.1	4.6
1998	-1.2	-1.9	-0.1	3.1	9.6	13.8	16.7	16.4	12.7	6.6	1.2	-2.3	6.2
1999	-5.3	-4.0	-1.6	2.3	8.0	14.6	18.4	16.9	13.5	4.4	3.1	-1.9	5.7

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2000	-6.9	-4.1	-0.1	2.9	9.1	14.2	15.3	16.4	11.5	5.7	0.9	-6.2	4.9
2001	-6.8	-5.1	-2.1	3.3	9.2	15.4	14.7	18.1	11.3	5.8	2.9	-0.6	5.5
2002	-1.7	-4.1	0.0	4.7	7.8	13.3	17.5	17.6	12.9	6.3	1.5	-4.4	5.9
2003	-7.2	-6.7	-2.9	2.7	6.8	13.8	17.7	19.2	13.9	5.6	3.3	-2.4	5.3
2004	-8.7	-5.0	0.2	4.6	10.6	13.8	17.2	16.8	13.3	6.8	1.6	-3.8	5.6
2005	-6.3	-5.6	1.7	2.5	6.6	15.6	18.2	19.1	13.1	8.8	2.9	-4.1	6.1
2006	-1.8	-5.3	-1.7	3.1	9.6	15.6	18.9	17.0	11.7	5.9	4.4	-0.1	6.4
2007	-2.7	-7.1	-2.6	2.2	8.4	13.9	17.3	16.9	12.6	11.2	0.5	-3.0	5.6
2008	-4.0	-4.1	-3.1	4.1	7.4	15.8	18.5	16.0	12.7	5.1	0.8	-1.7	5.6
2009	-7.9	-3.9	-1.9	4.2	9.6	13.8	15.8	18.1	11.2	6.0	4.8	-3.1	5.6
2010	-5.8	-4.2	1.5	5.5	10.0	15.9	19.1	17.3	14.6	7.3	1.9	-4.2	6.6
2011	-7.3	-5.4	-0.8	5.2	10.9	14.9	18.6	17.4	15.8	7.8	4.0	-1.5	6.7
2012	-3.2	-2.6	3.0	3.8	11.9	13.9	18.5	17.4	12.7	9.4	0.0	-0.1	7.1
2013	-4.5	-3.9	-1.4	3.4	8.3	15.0	20.3	15.3	10.8	7.0	0.1	-2.6	5.7
2014	-8.7	-7.7	-5.1	1.7	8.7	13.4	17.3	14.5	12.3	8.3	0.5	-0.5	4.6
2015	-7.5	-13.6	-4.4	2.1	10.0	14.1	18.1	17.0	14.3	5.5	2.7	3.7	5.2
2016	-5.3	-4.8	1.2	1.9	8.6	13.0	18.1	17.8	13.9	7.0	1.8	-3.1	5.8
Average	-6.4	-5.9	-2.1	2.4	7.8	13.2	16.7	15.8	11.5	5.5	0.9	-3.7	4.6
Max	-1.2	-1.8	3.0	5.5	11.9	15.9	20.3	19.2	15.8	11.2	4.8	3.7	7.1
Min	-12.3	-13.6	-5.5	-1.1	4.1	10.3	12.3	12.2	7.7	1.4	-2.3	-9.9	2.7

Min

Max

Barometric Pressure

Barometric pressure is measured at the 2-meter level. The pressure sensors are connected to R.M. Young model 61002 pressure ports to reduce errors due to blowing winds. The sensors are sent off-site for calibration. Average daily pressure for 2016 is plotted in Figure 16. The lowest pressure, 982.5 mbar, occurred on January 31st. Monthly data plots of the 1-minute data for pressure are presented in Figures 17 through 28.

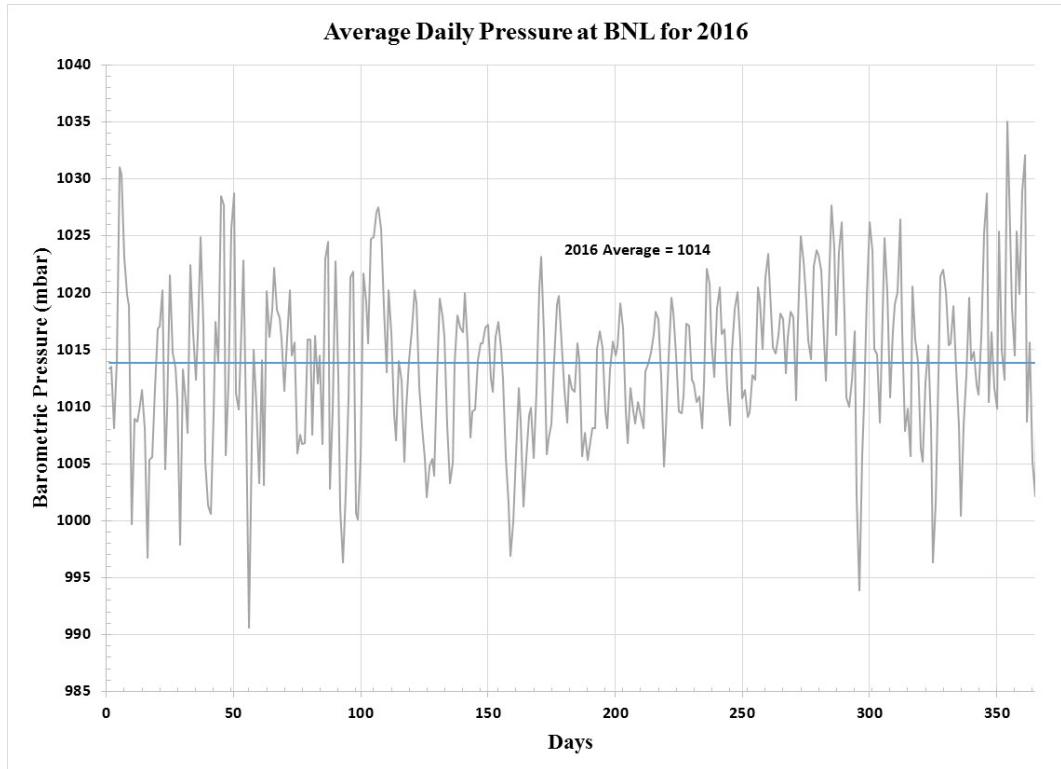


Figure 16 Average Daily Barometric Pressure at Brookhaven National Laboratory for 2016

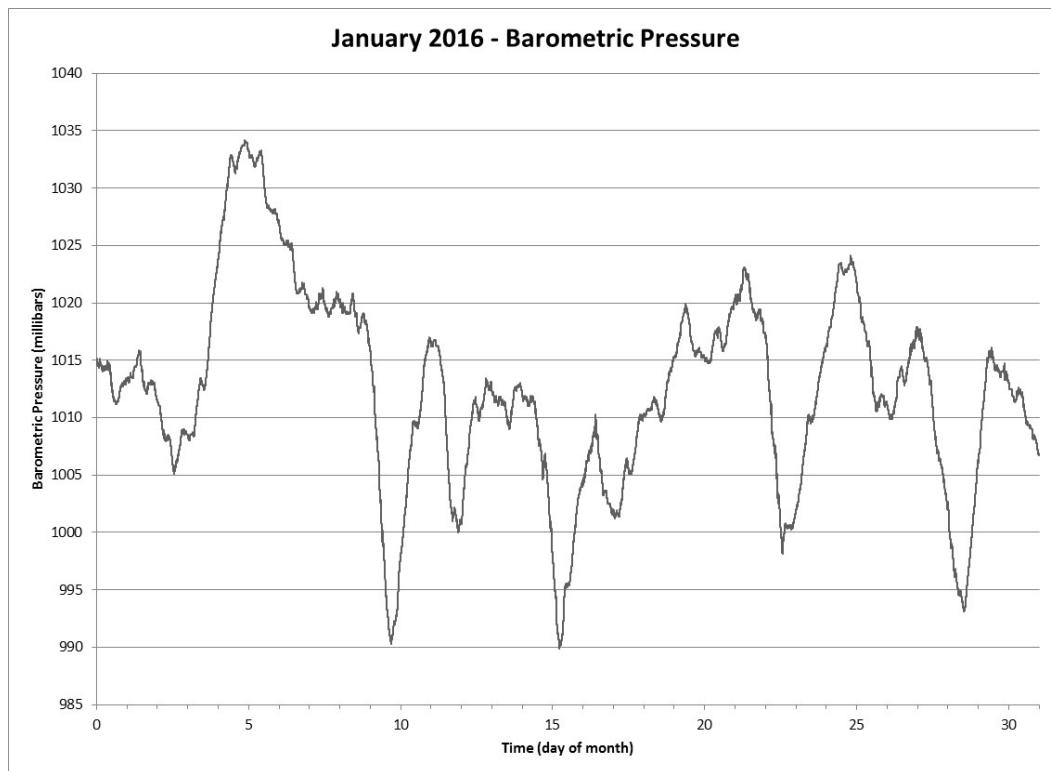


Figure 17 Barometric Pressure for the Month of January 2016

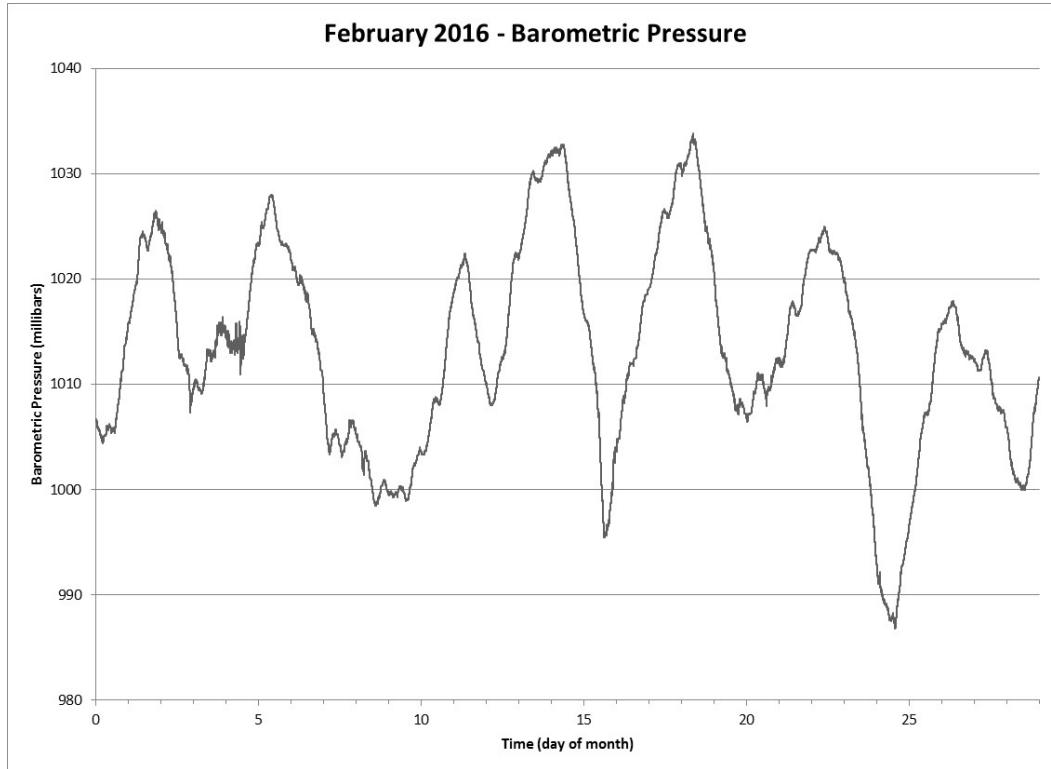


Figure 18 Barometric Pressure for the Month of February 2016

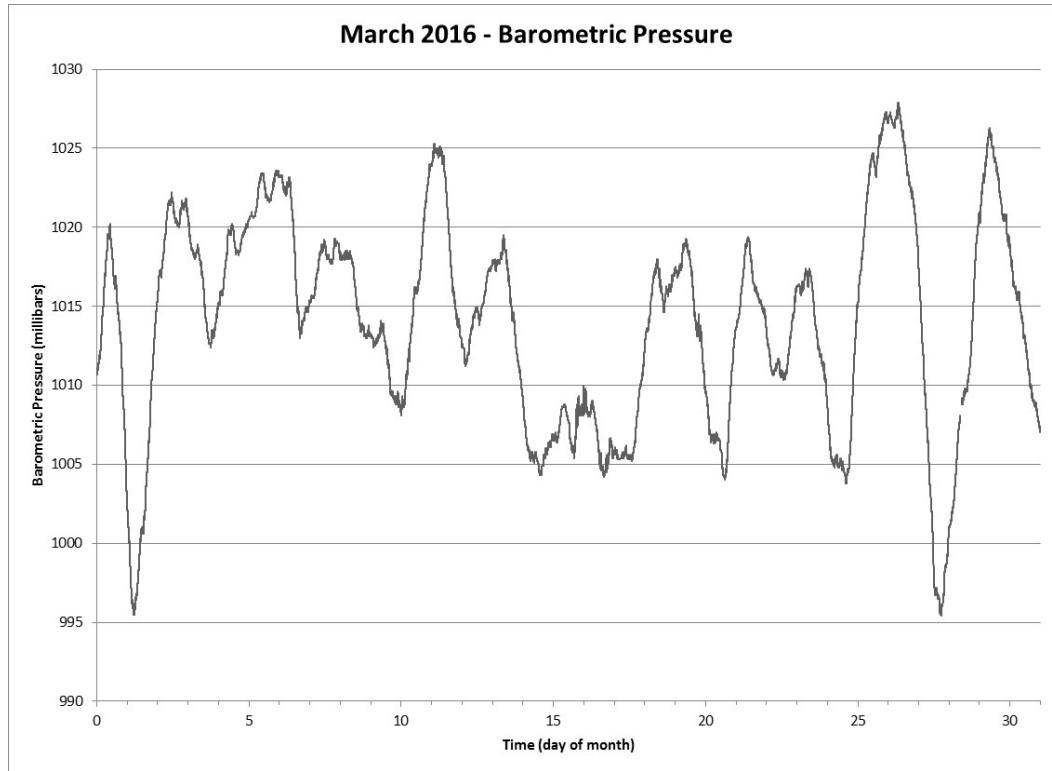


Figure 19 Barometric Pressure for the Month of March 2016

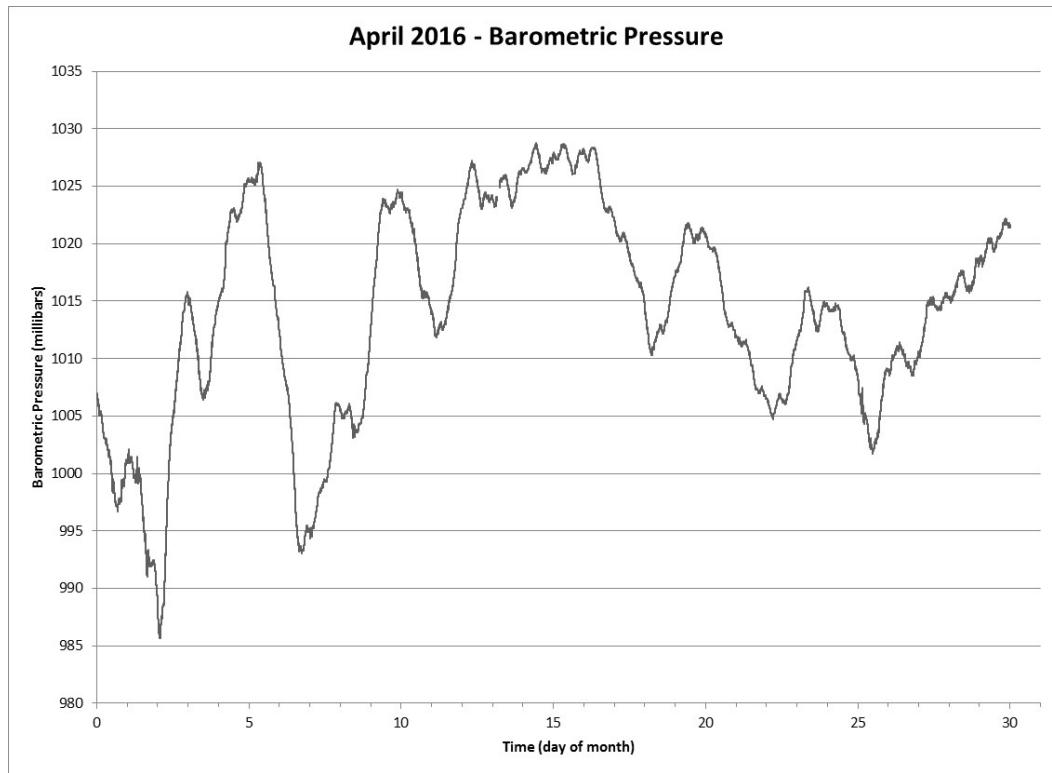


Figure 20 Barometric Pressure for the Month of April 2016

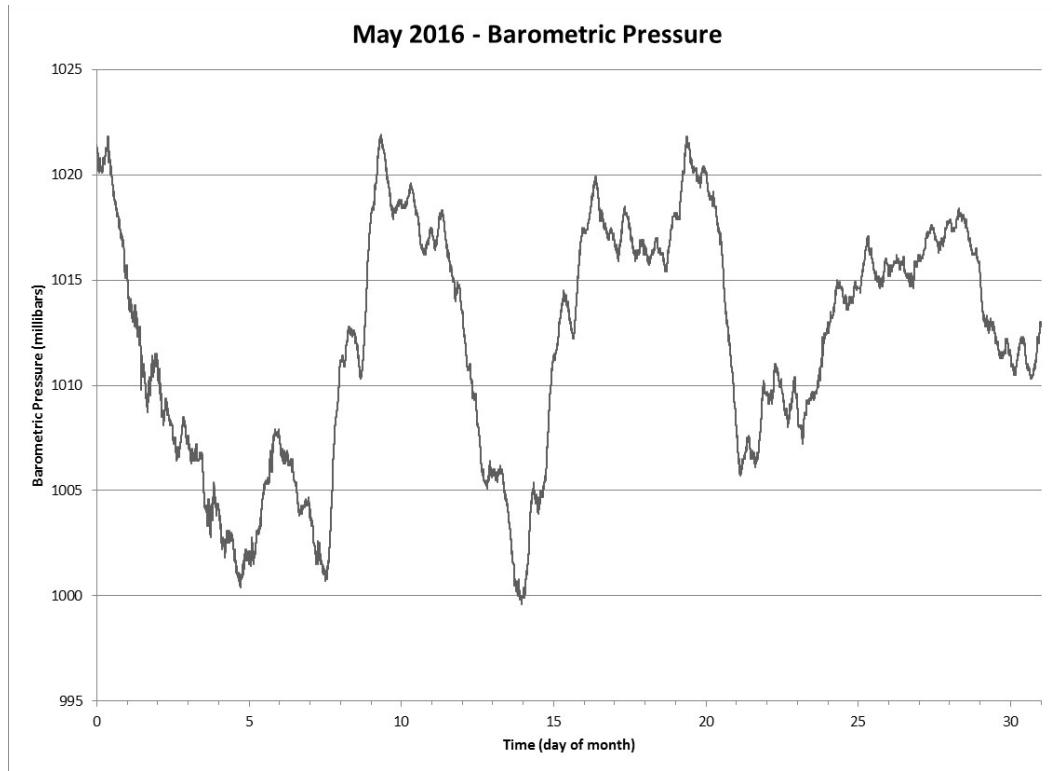


Figure 21 Barometric Pressure for the Month of May 2016

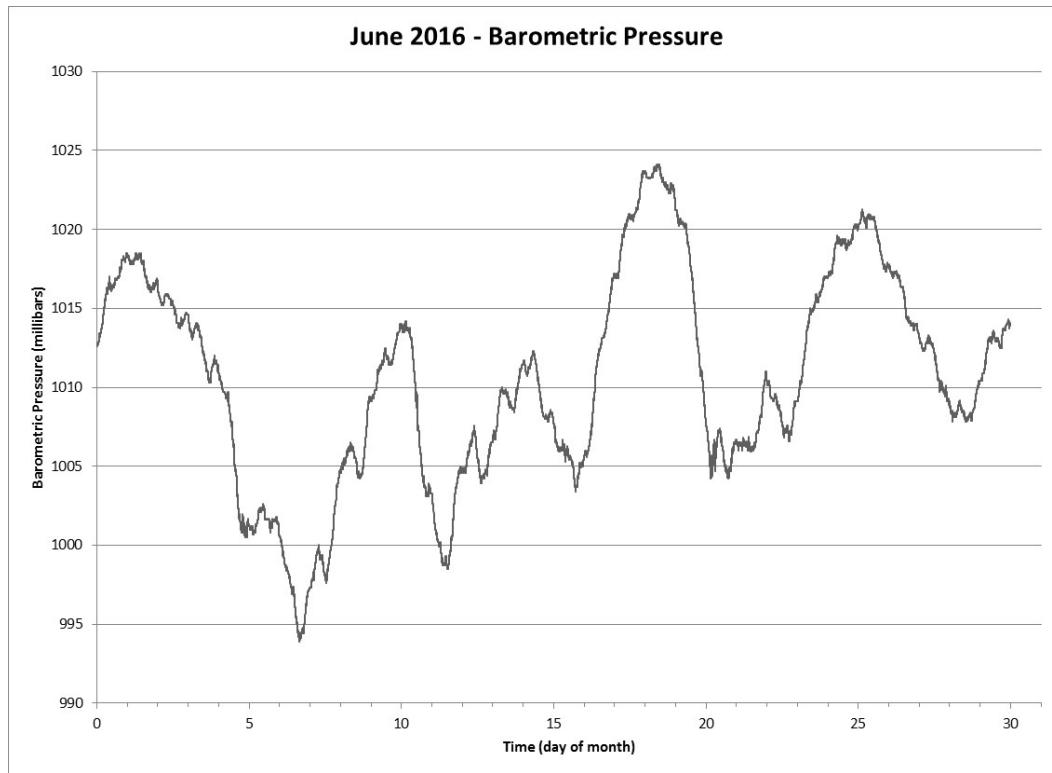


Figure 22 Barometric Pressure for the Month of June 2016

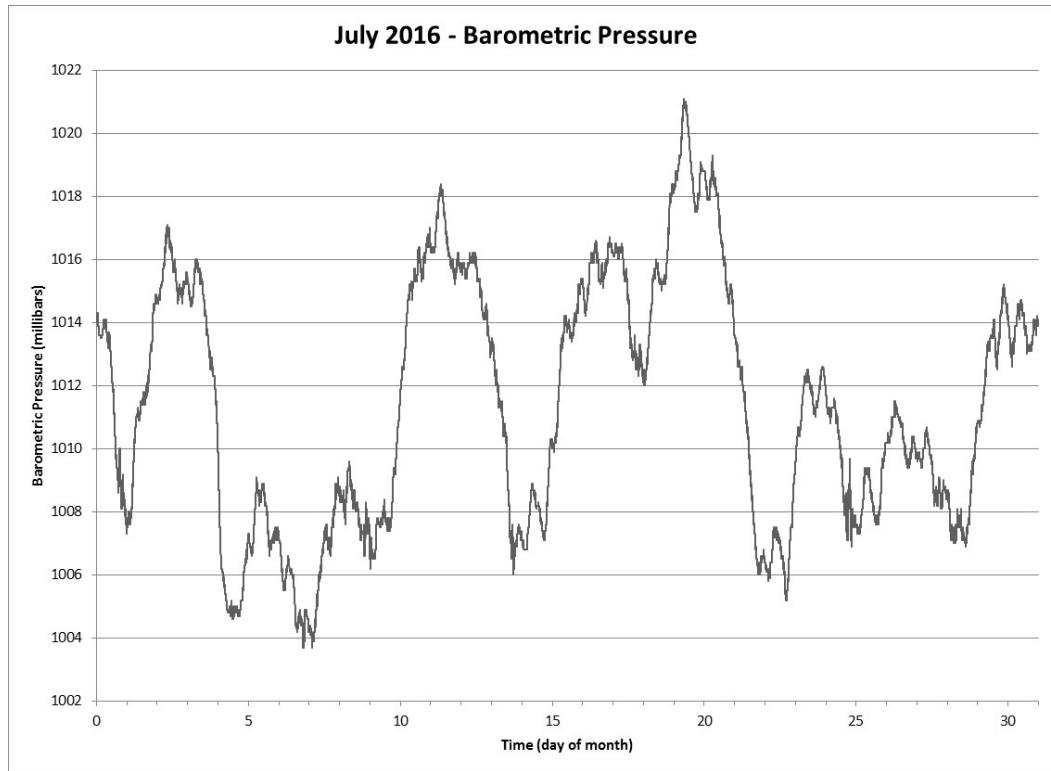


Figure 23 Barometric Pressure for the Month of July 2016

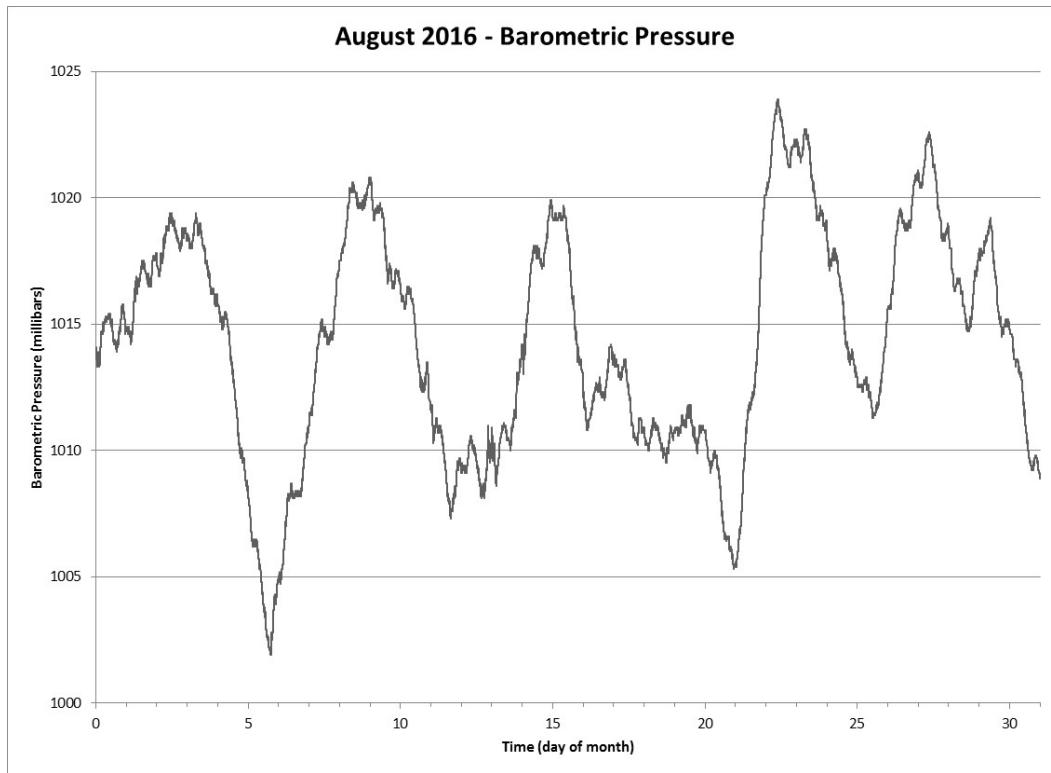


Figure 24 Barometric Pressure for the Month of August 2016

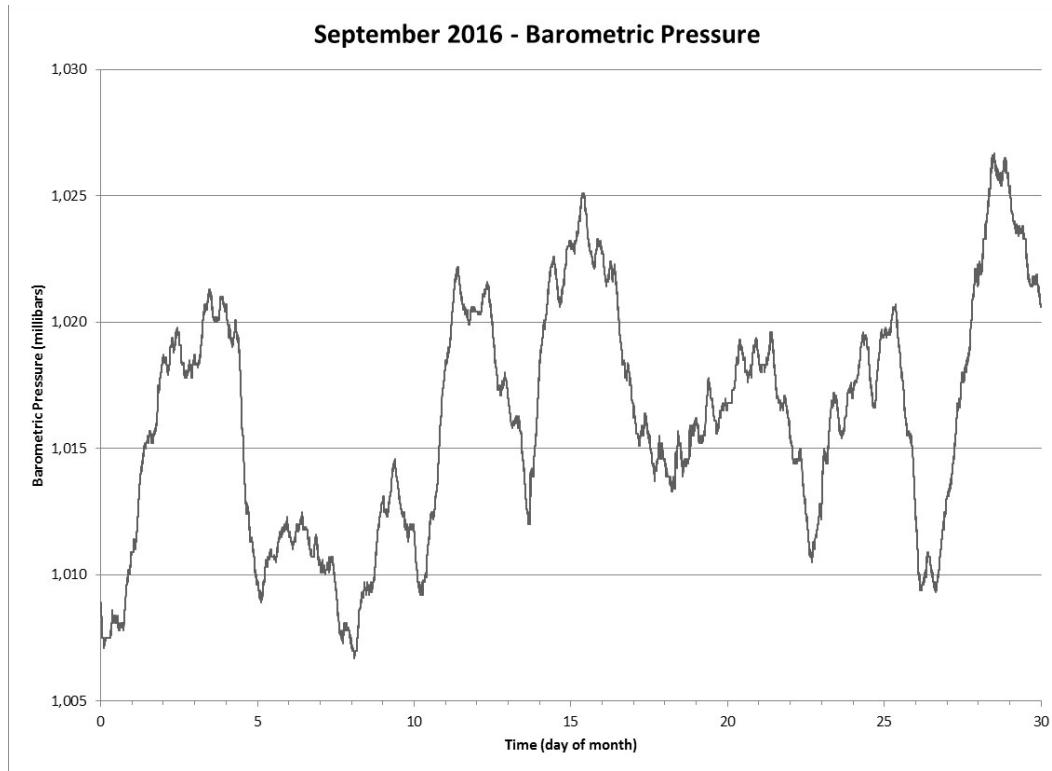


Figure 25 Barometric Pressure for the Month of September 2016

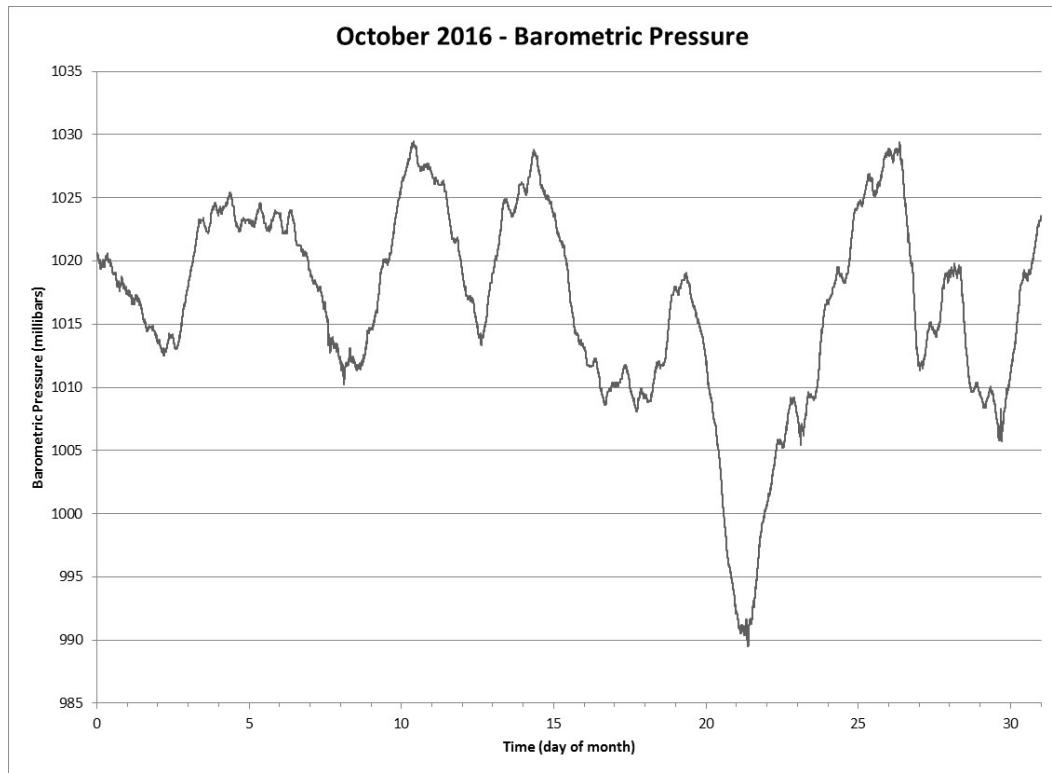


Figure 26 Barometric Pressure for the Month of October 2016

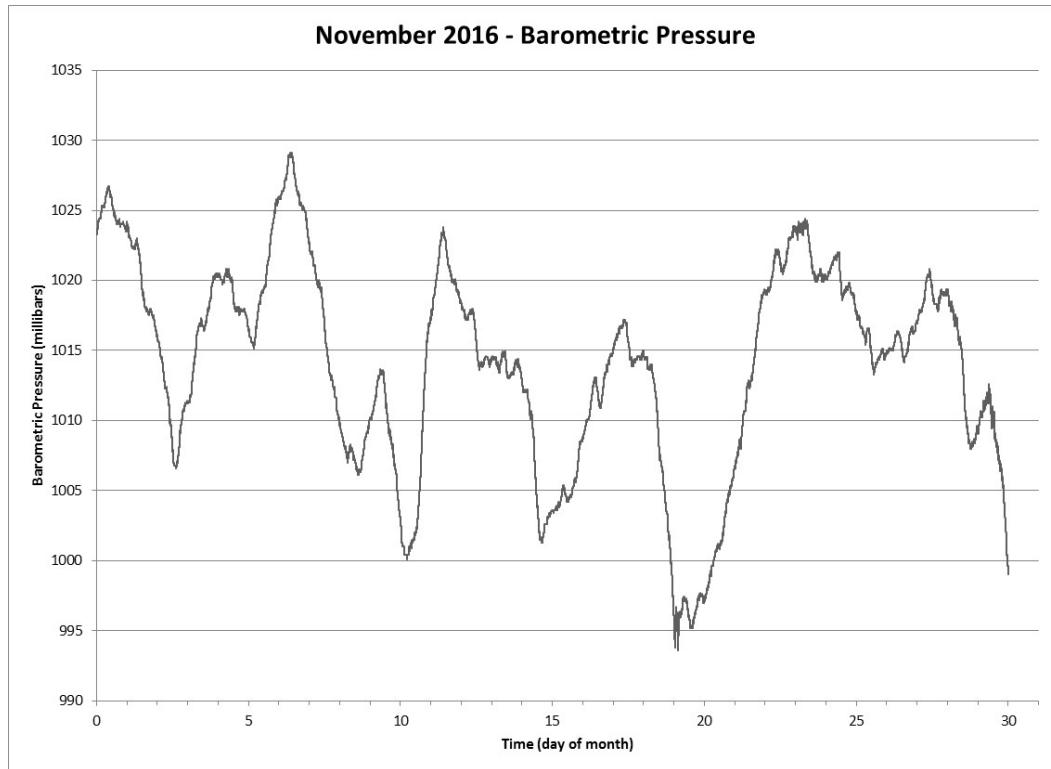


Figure 27 Barometric Pressure for the Month of November 2016

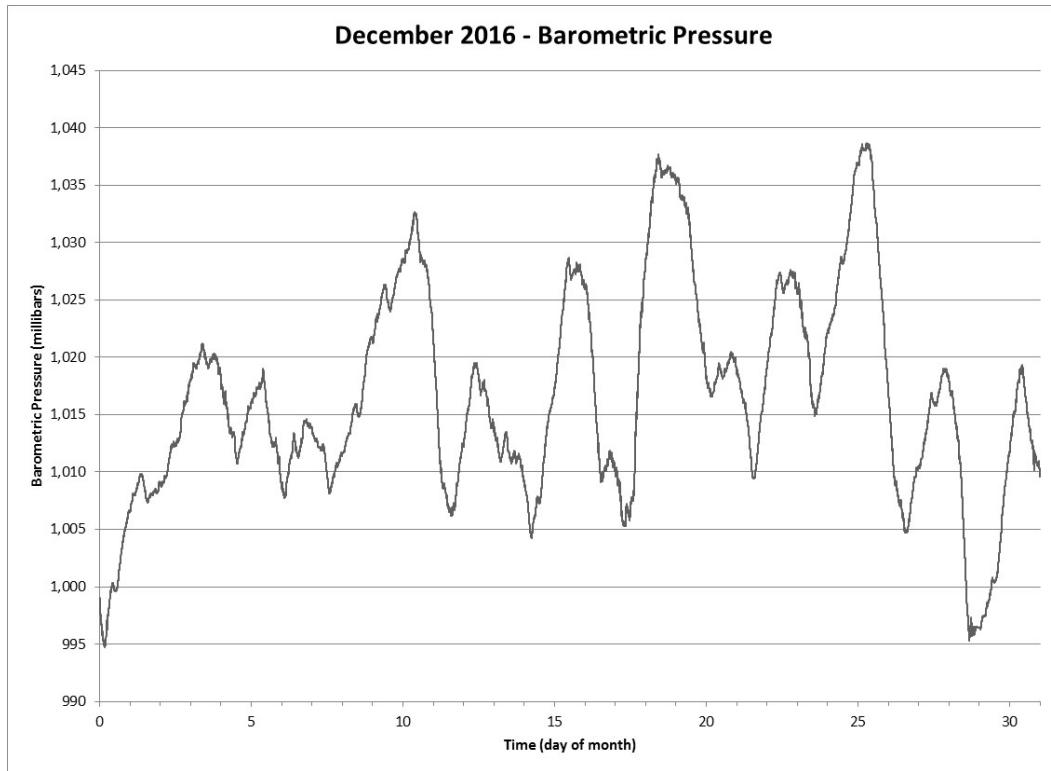


Figure 28 Barometric Pressure for the Month of December 2016

Relative Humidity

Relative Humidity is measured at the 2-meter level. The sensors are calibrated on site and maintained to $\pm 4\%$. The relative humidity sensor is calibrated, in the laboratory, using saturated salt baths. The use of saturated salt baths is one of the oldest methods for generating humidity at different levels. The RH value is a function of the chemical properties of the salt when mixed with water, with different saturated salt solutions yielding different RH values. Although cumbersome, saturated salt solutions are very reliable. The saturated salt solutions are easy to make and result in a fairly constant humidity over a reasonable temperature range. BNL Met Services uses saturated aqueous salt solutions as described in ASTM E104-02 to obtain a three point calibration of the RH probes. Specific humidity calibration chamber covers that fit each probe type are used and separate chambers for each salt solution. The reference solutions are stored in sealed chambers. The specific solutions include; Sodium Chloride (NaCl) for $75.5 \pm 0.2\%$ RH @ 20°C , Sodium Bromide (NaBr) for $59.1 \pm 0.5\%$ RH @ 20°C and Magnesium Chloride (MgCl) for $33.1 \pm 0.2\%$ RH @ 20°C . In contrast, the Campbell (Rotonic) HC2-S3 has a stated accuracy of $\pm 0.8\%$ @ 23°C . The ANS requirement is $\pm 4\%$. If the probe fails to meet the $\pm 4\%$ it must be replaced.

The average daily humidity at BNL for 2016 was 73 %. The average daily low humidity was 47 %. The average daily high humidity was 93 %. Daily average humidity is plotted in Figure 29, daily minimum in Figure 30 and daily maximum humidity in Figure 31. Monthly data plots of the 1-minute data for relative humidity are presented in Figures 32 through 43.

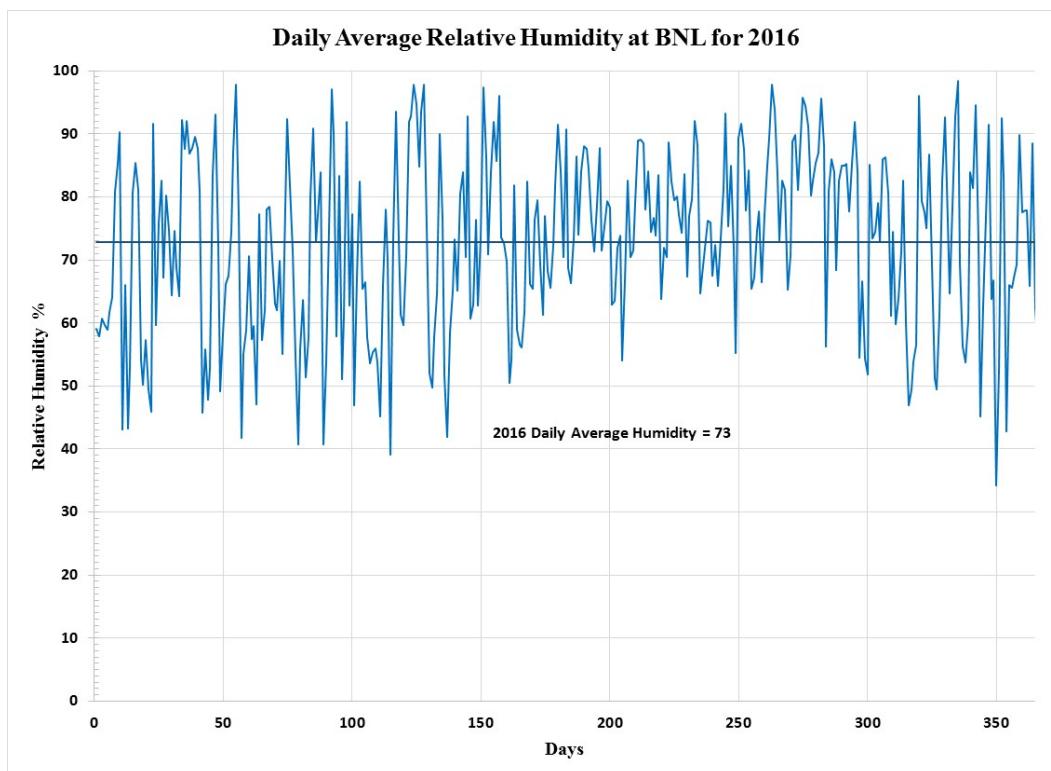


Figure 29 Daily Mean Relative Humidity at Brookhaven National Laboratory for 2016

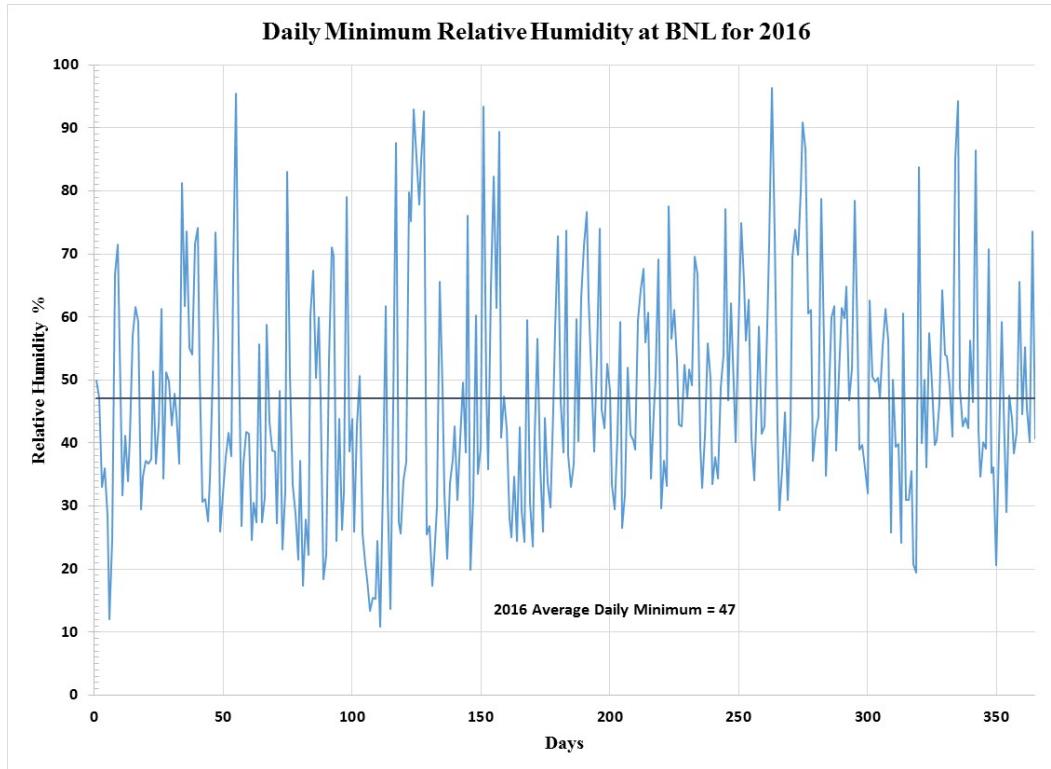


Figure 30 Minimum Daily Humidity at Brookhaven National Laboratory for 2016

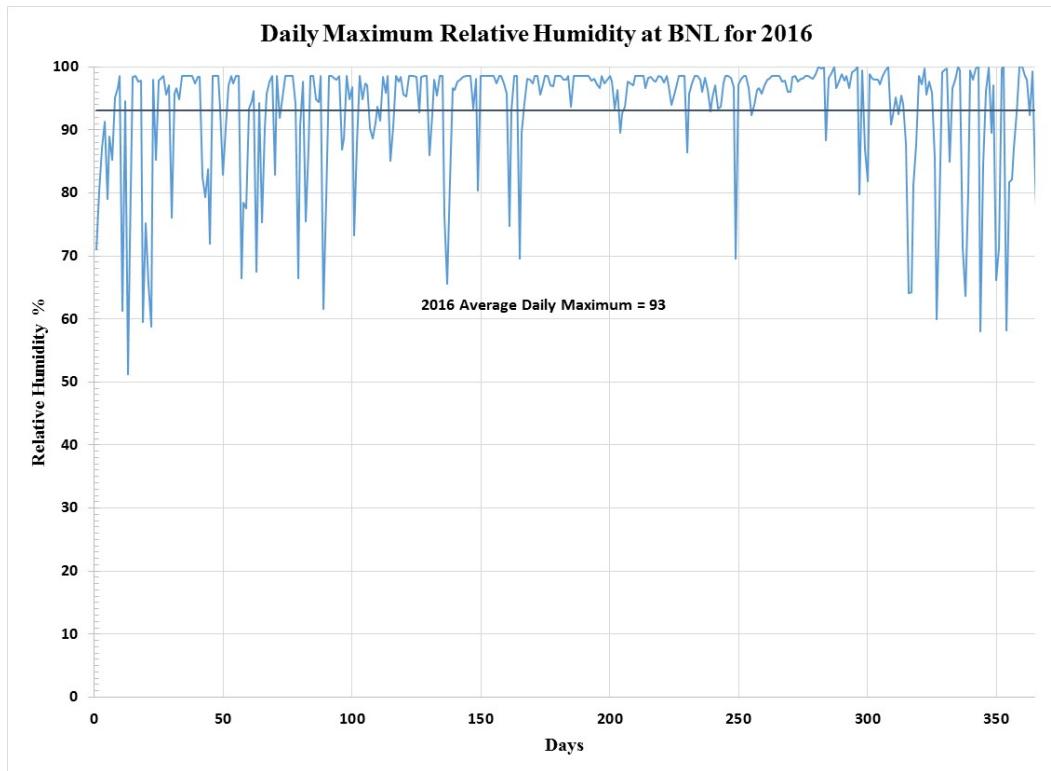


Figure 31 Maximum Daily Humidity at Brookhaven National Laboratory for 2016

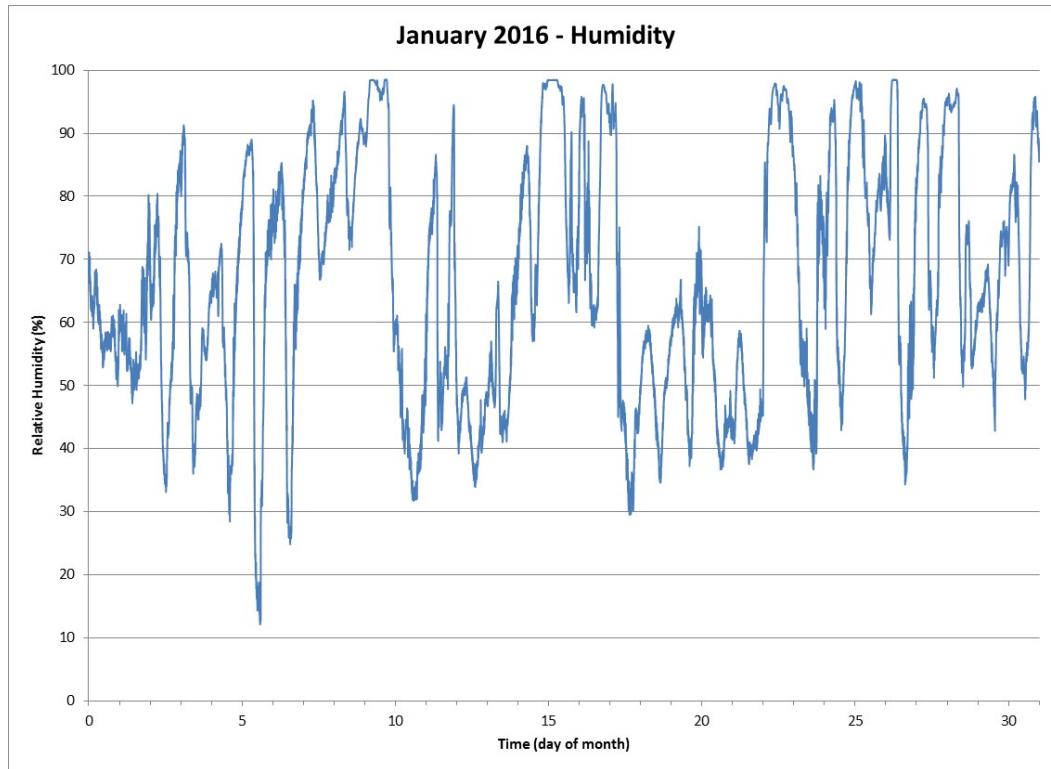


Figure 32 Relative Humidity for the Month of January 2016

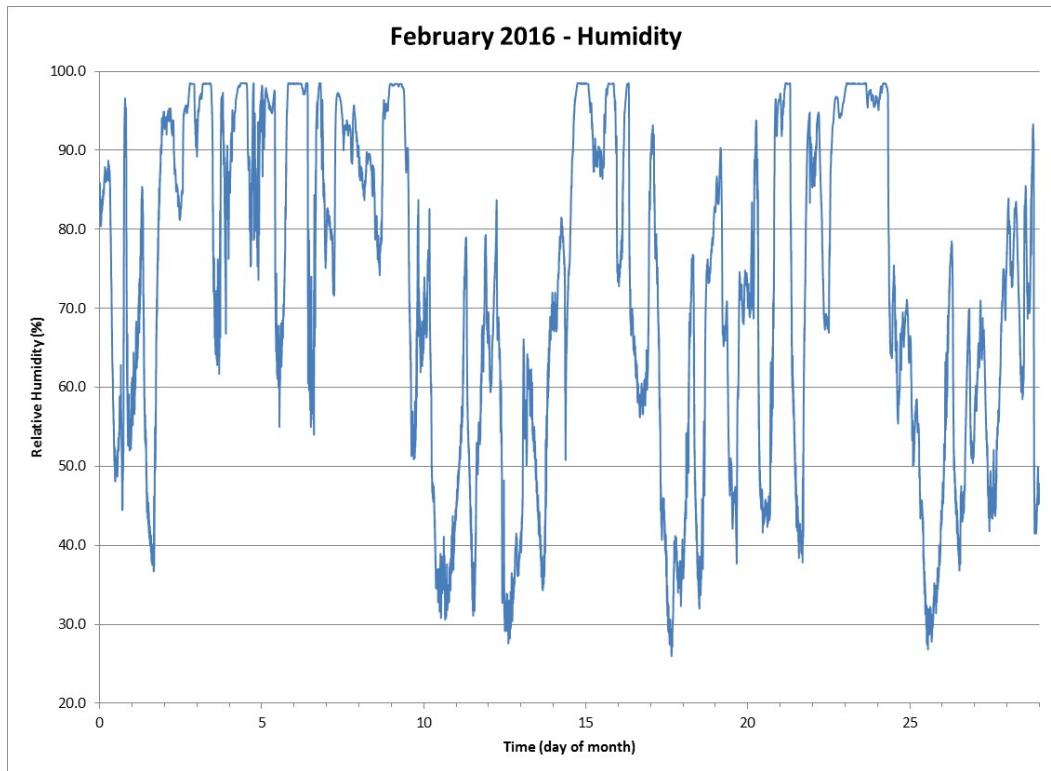


Figure 33 Relative Humidity for the Month of February 2016

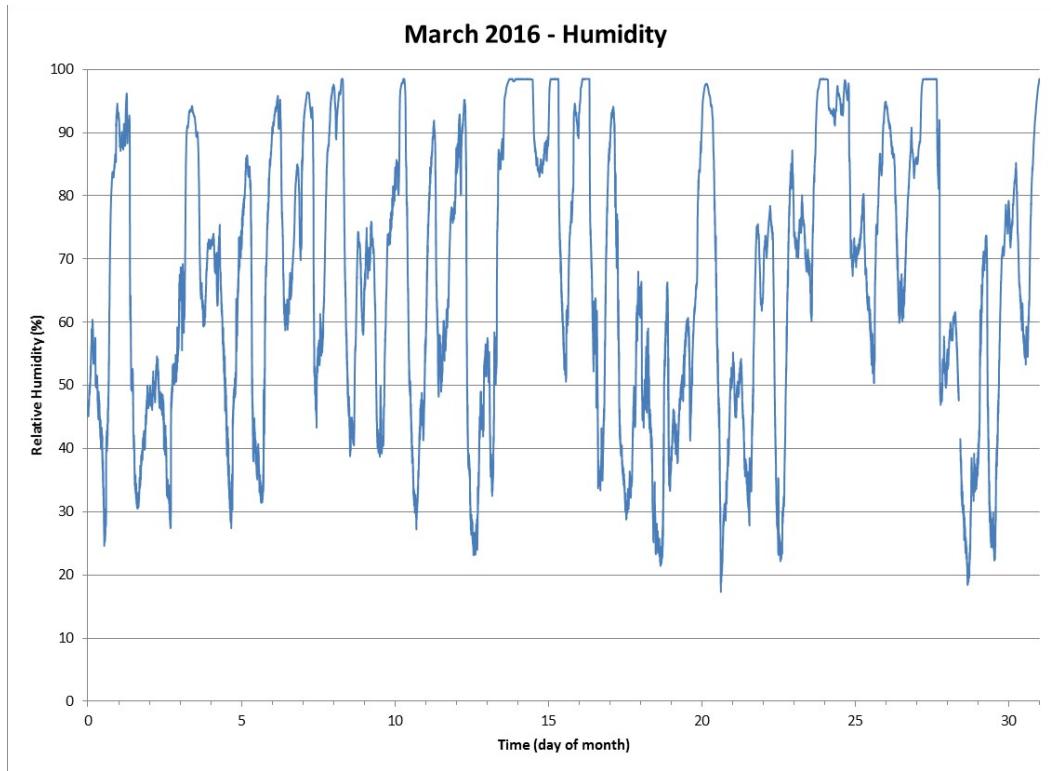


Figure 34 Relative Humidity for the Month of March 2016

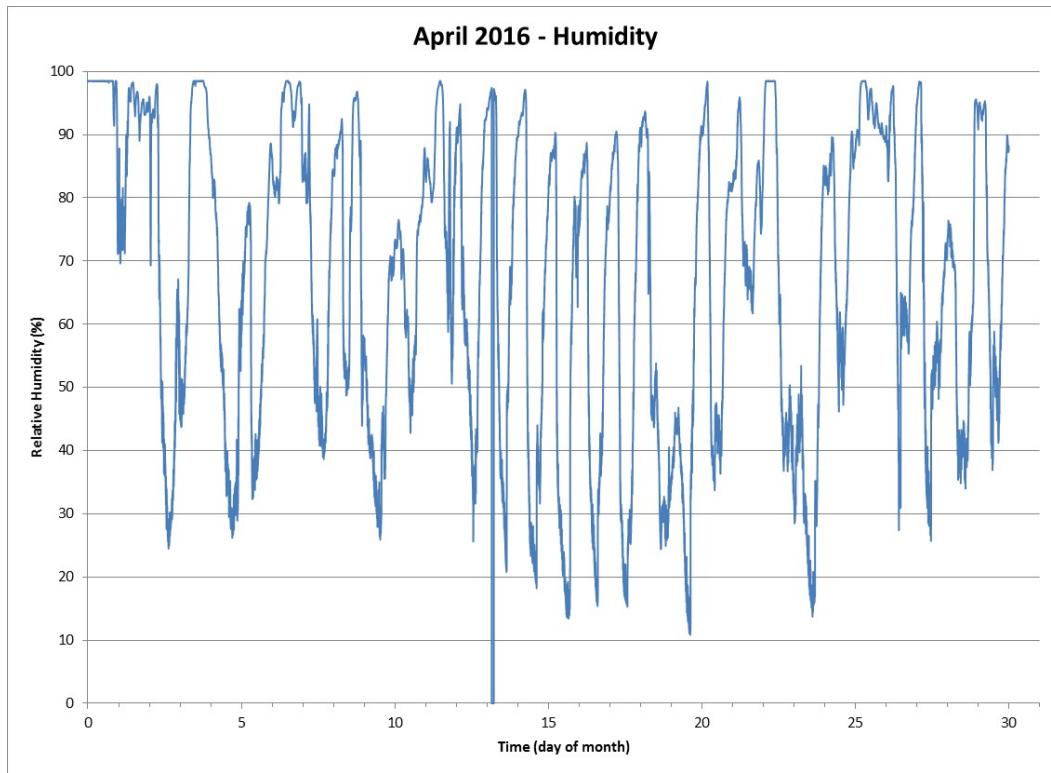


Figure 35 Relative Humidity for the Month of April 2016

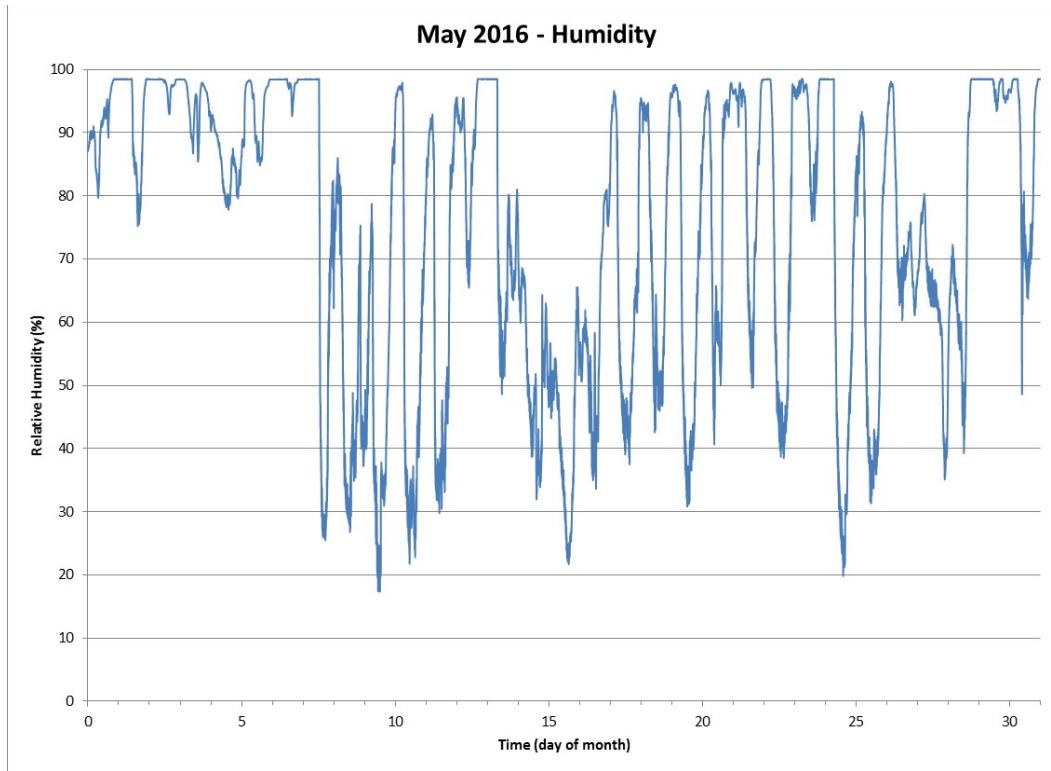


Figure 36 Relative Humidity for the Month of May 2016

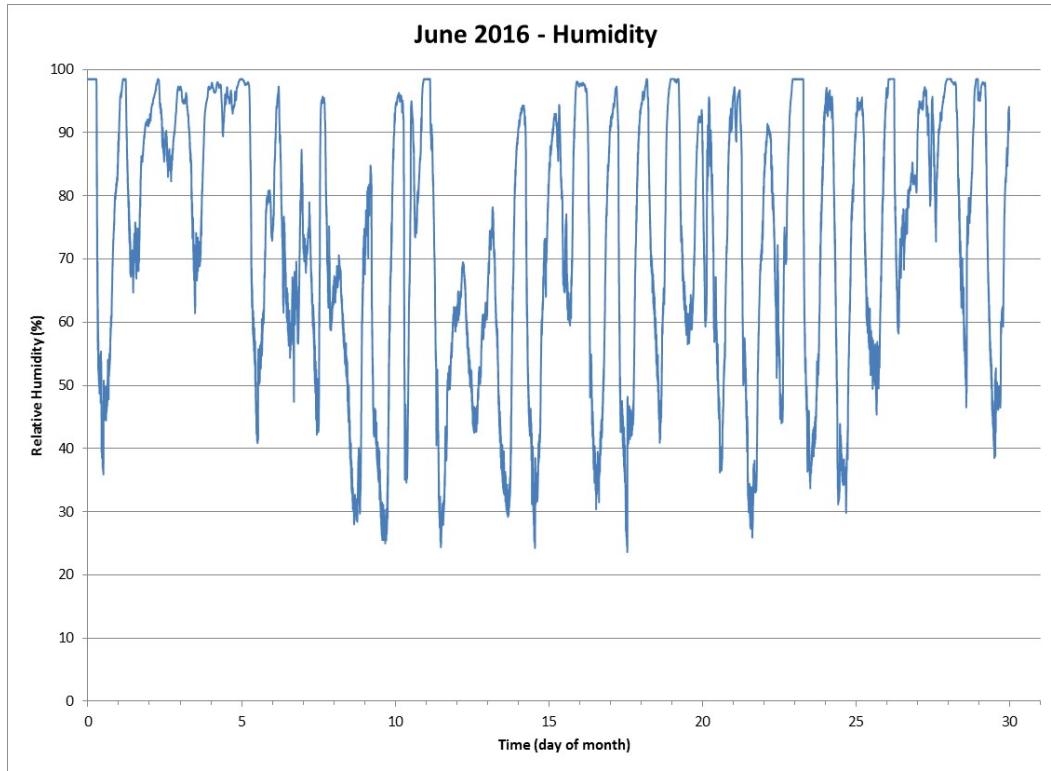


Figure 37 Relative Humidity for the Month of June 2016

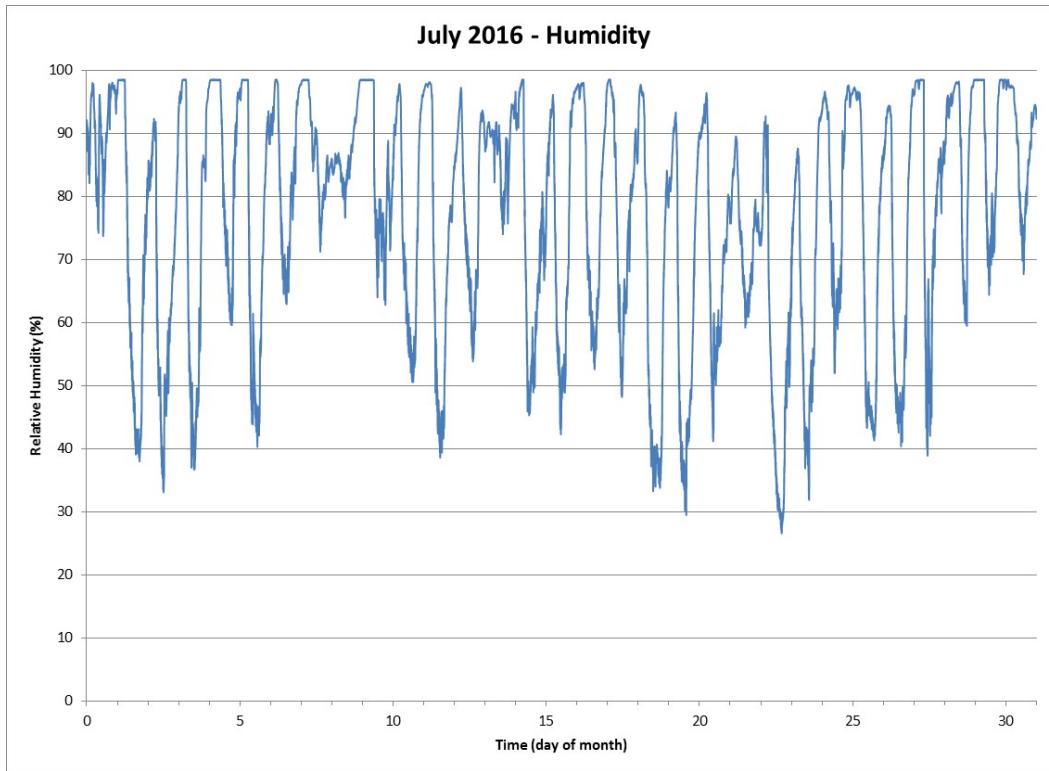


Figure 38 Relative Humidity for the Month of July 2016

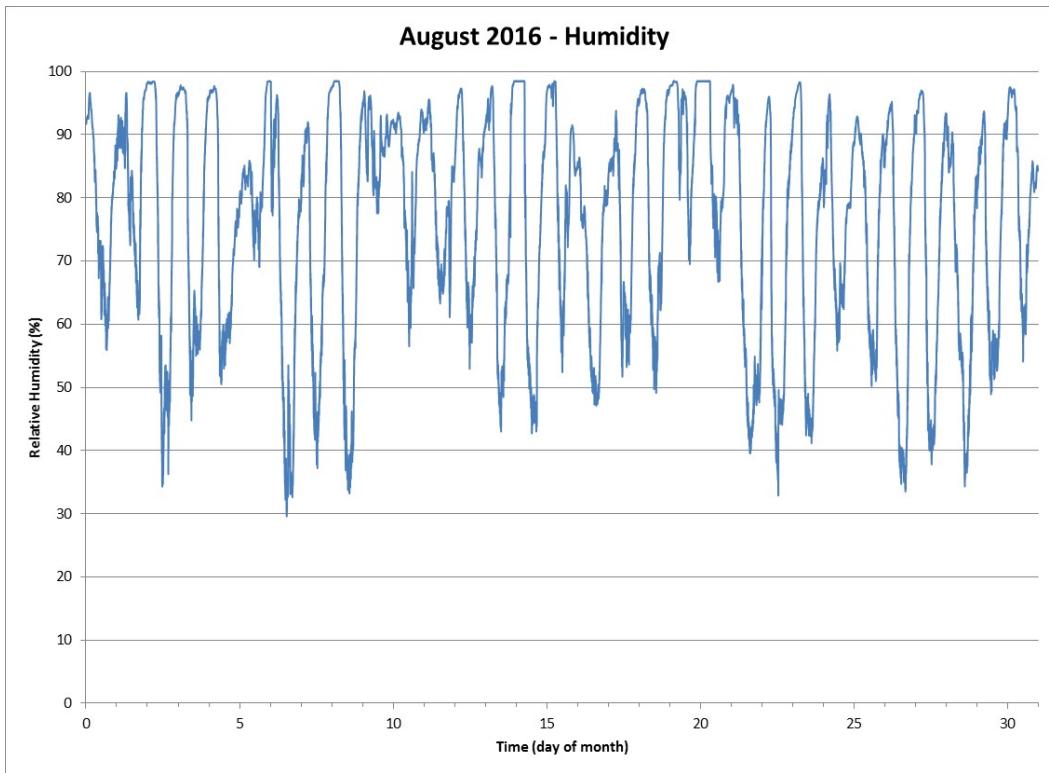


Figure 39 Relative Humidity for the Month of August 2016

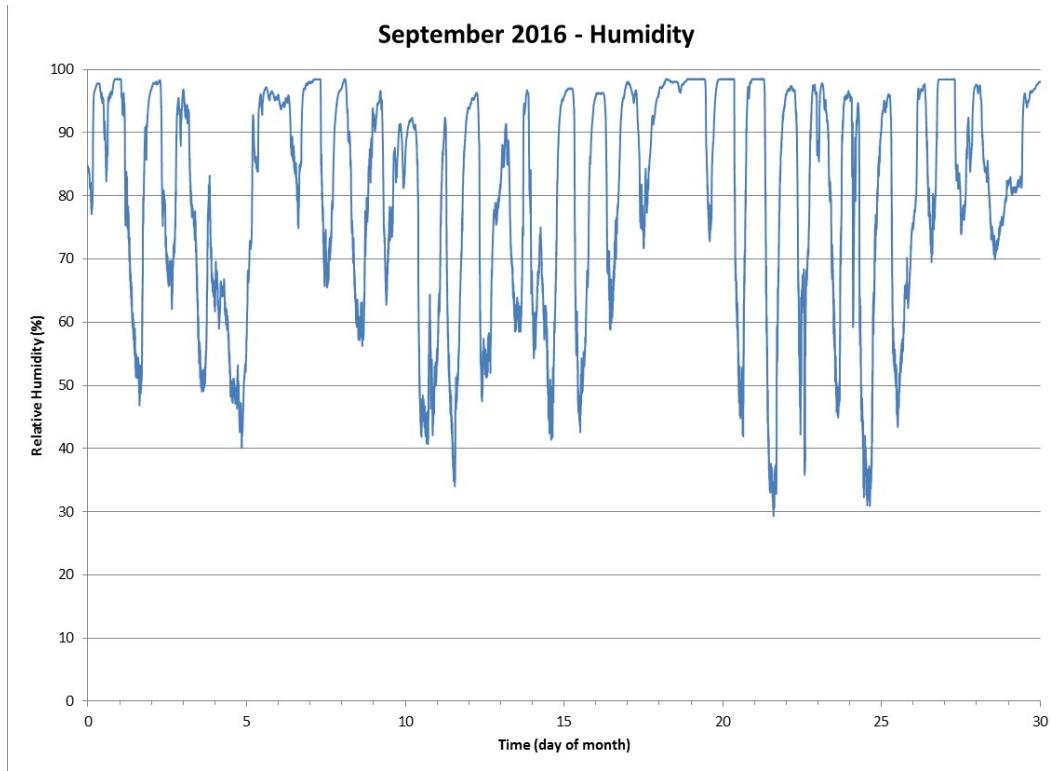


Figure 40 Relative Humidity for the Month of September 2016

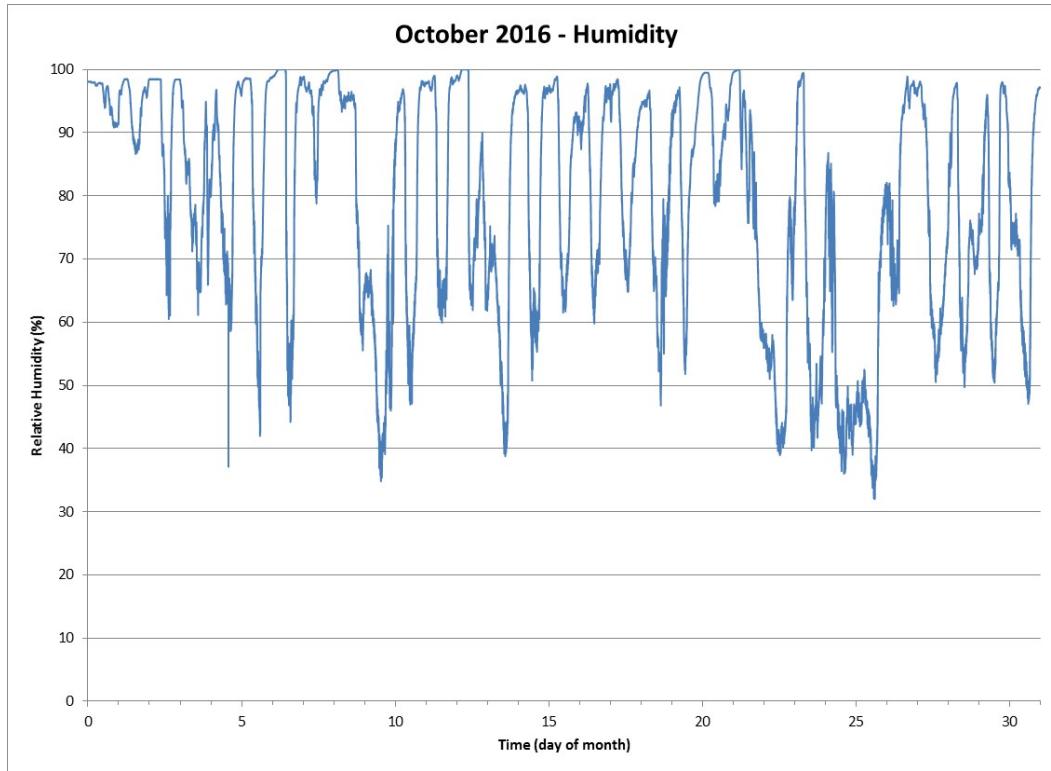


Figure 41 Relative Humidity for the Month of October 2016

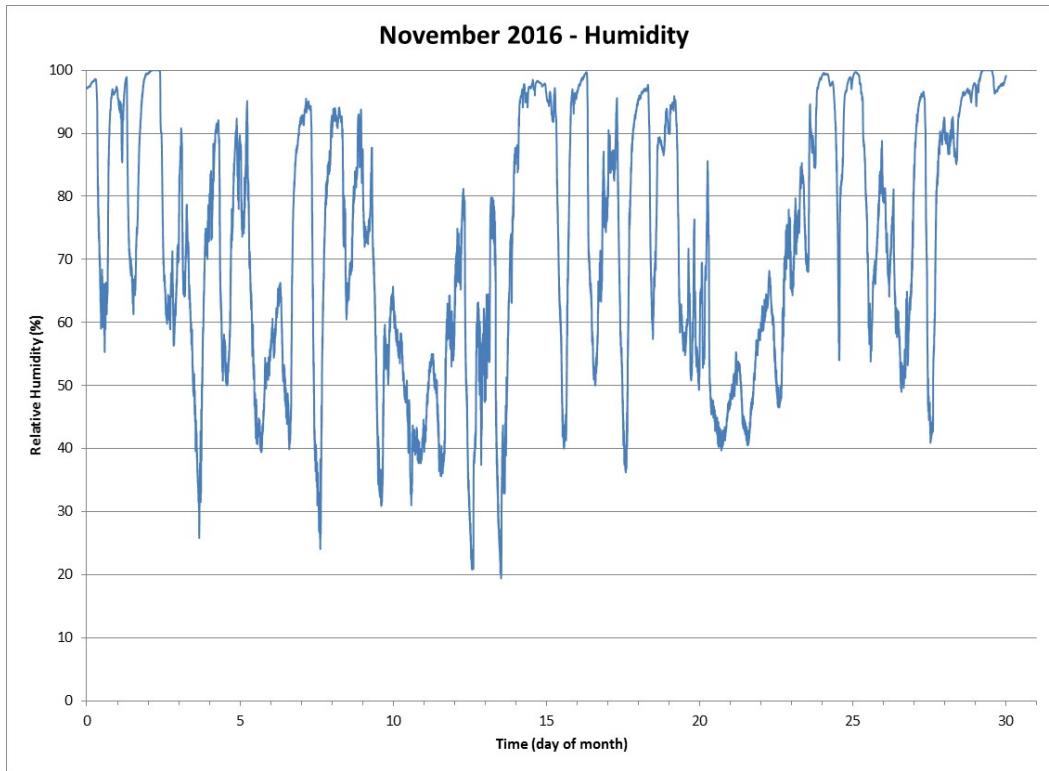


Figure 42 Relative Humidity for the Month of November 2016

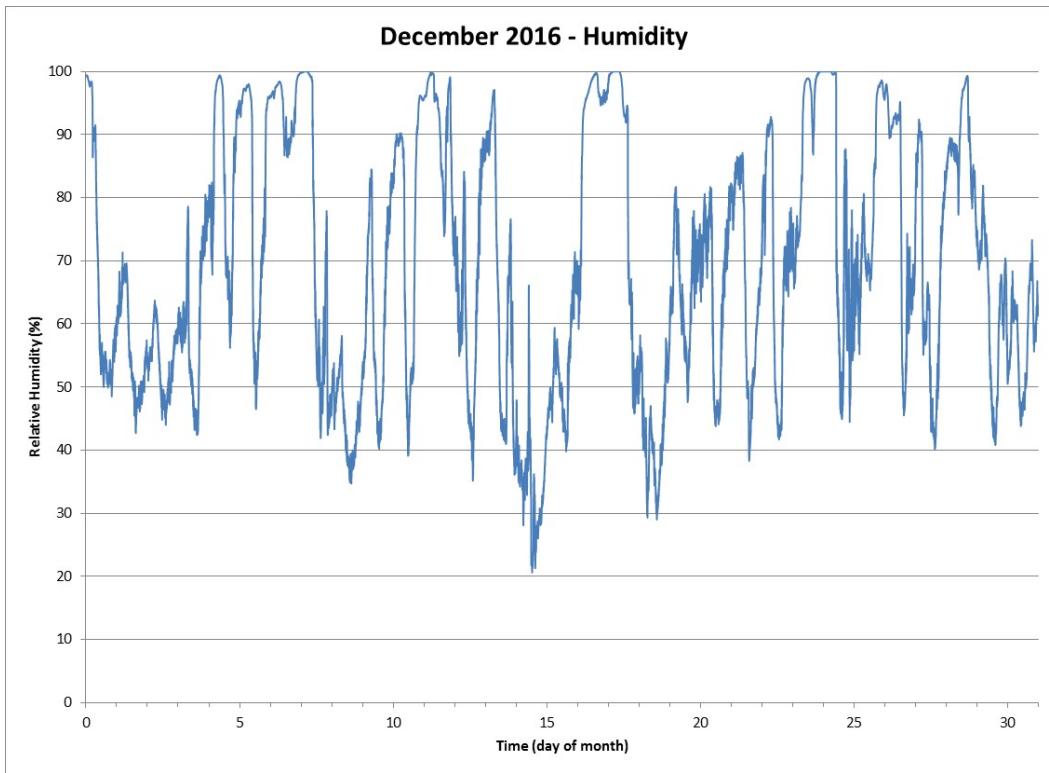


Figure 43 Relative Humidity for the Month of December 2016

Rainfall

Rainfall is measured using a 12" NovaLynx 2500 electrically heated (for snowfall events), tipping bucket rain gauges which are calibrated annually. The gauges measure tips for each 0.01" of rain. Calibration is accomplished by BNL personnel using the NovaLynx Calibration Assembly (model 260-2595) and is completed in-situ. Accuracy is $\pm 1\%$ for 1 to 3 inches per hour rainfall and $\pm 3\%$ for 0 to 6 inches per hour. If the test results are outside this accuracy requirement the tipping bucket is adjusted to bring it within specs. Total rainfall for the year was 38.9". Daily rainfall totals for the year are depicted in Figure 44. Monthly data charts of daily rainfall totals are presented in Figures 45 through 56. Table 6 lists the historic monthly rainfall totals along with monthly averages, maximums and minimums from 1949 to present.

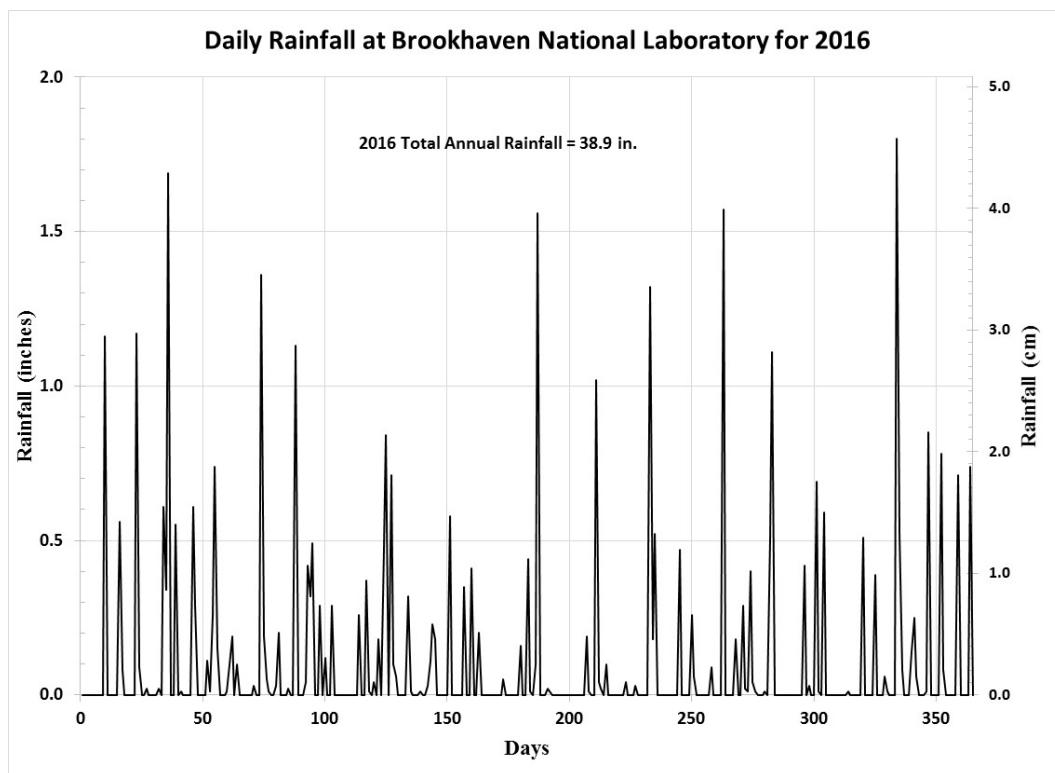


Figure 44 Daily Rainfall Totals at Brookhaven National Laboratory for 2016

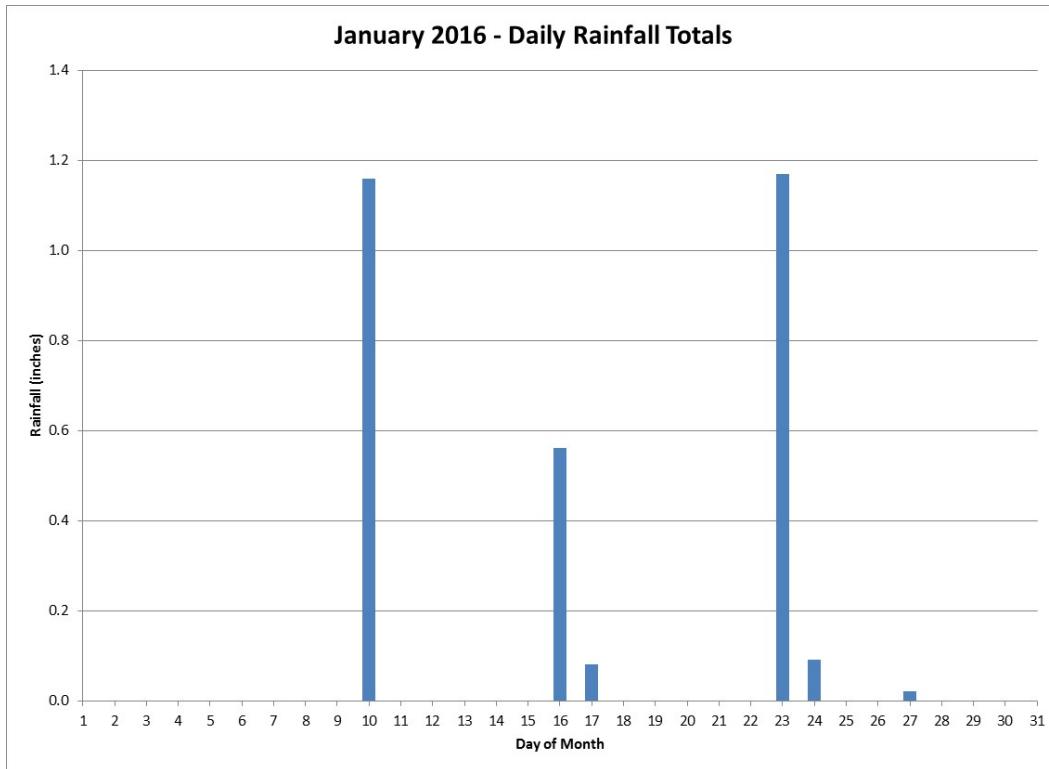


Figure 45 Daily Rainfall for the Month of January 2016

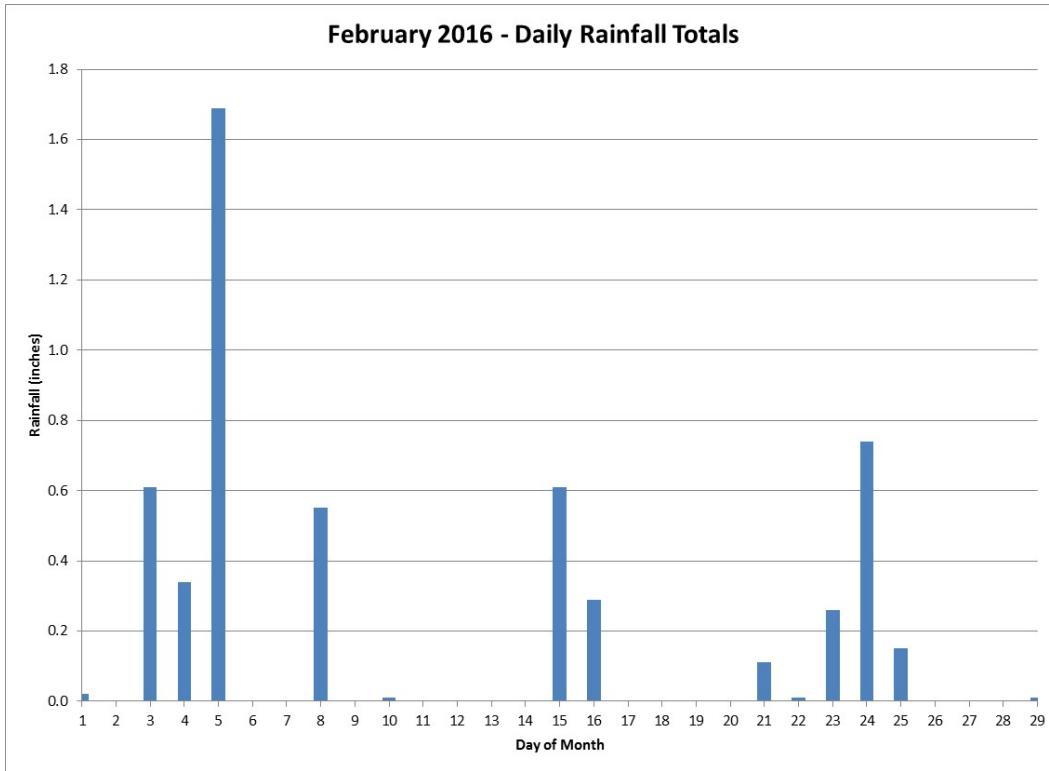


Figure 46 Daily Rainfall for the Month of February 2016

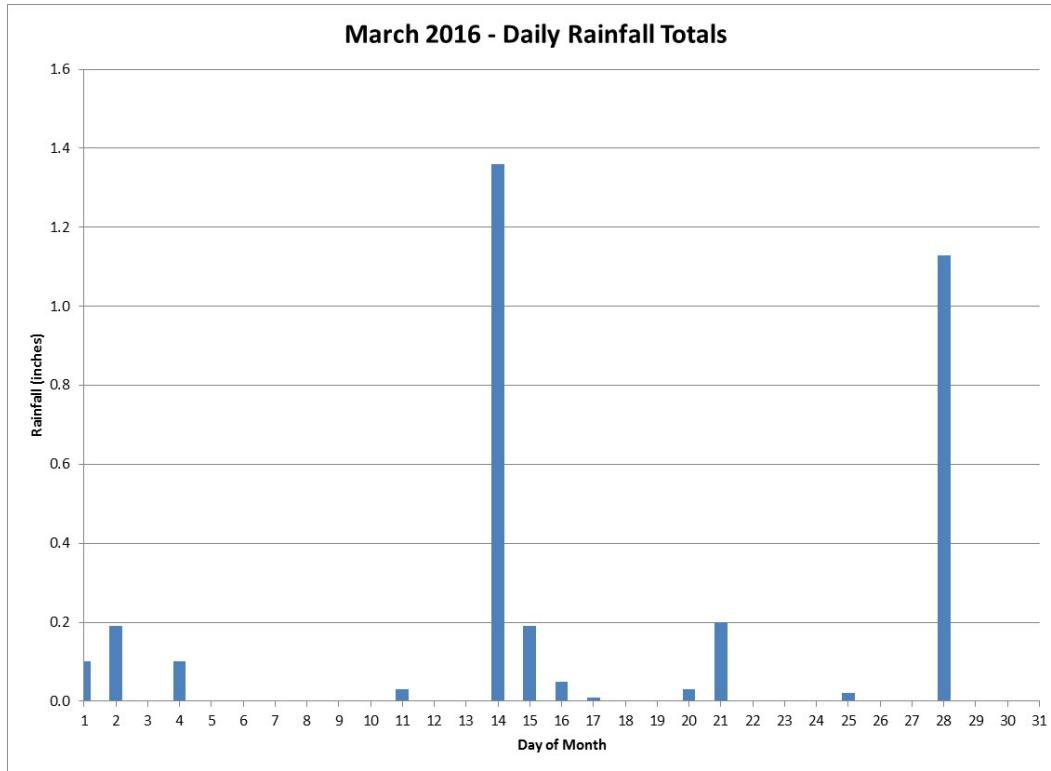


Figure 47 Daily Rainfall for the Month of March 2016

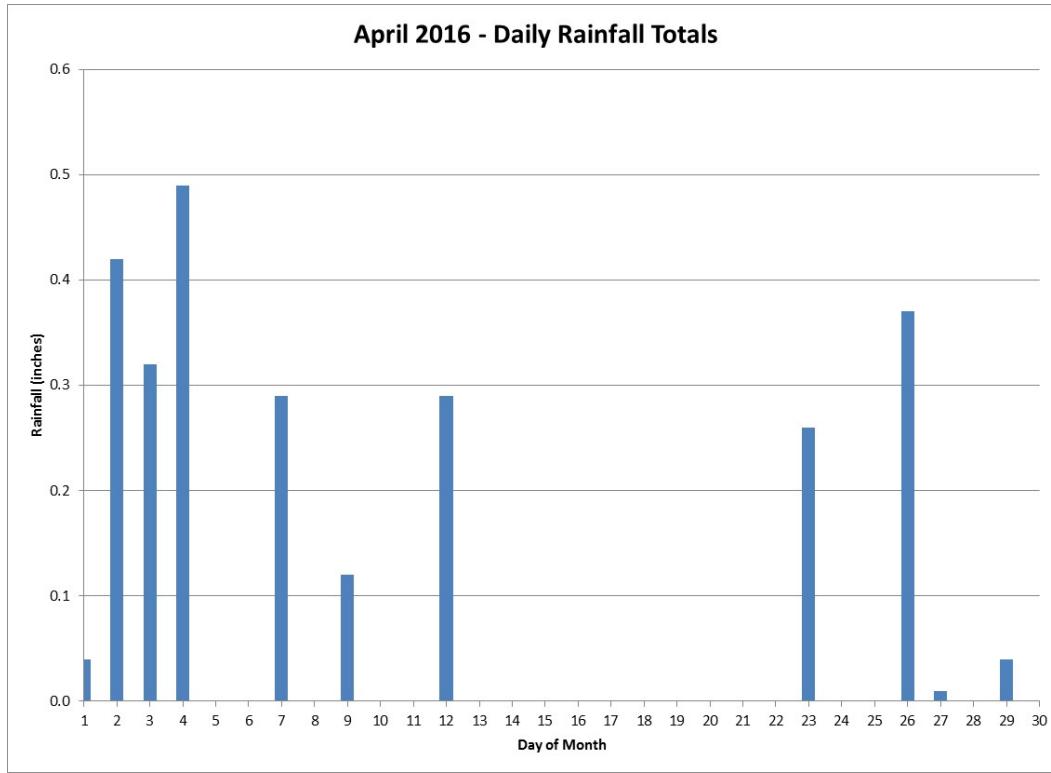


Figure 48 Daily Rainfall for the Month of April 2016

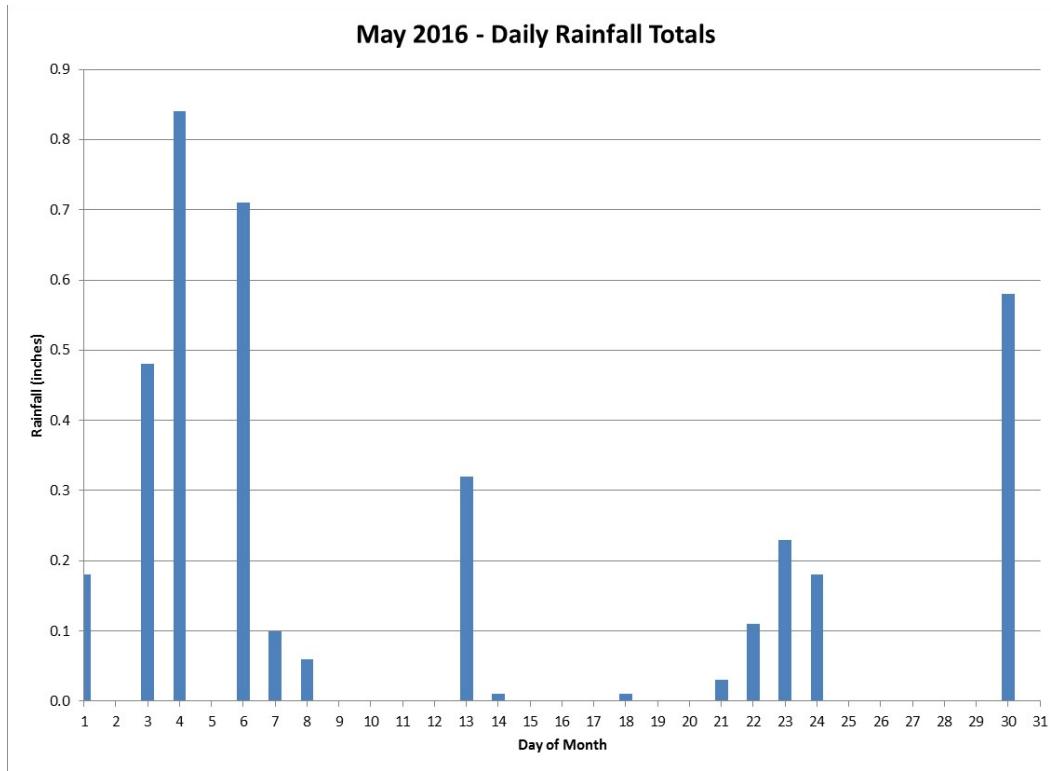


Figure 49 Daily Rainfall for the Month of May 2016

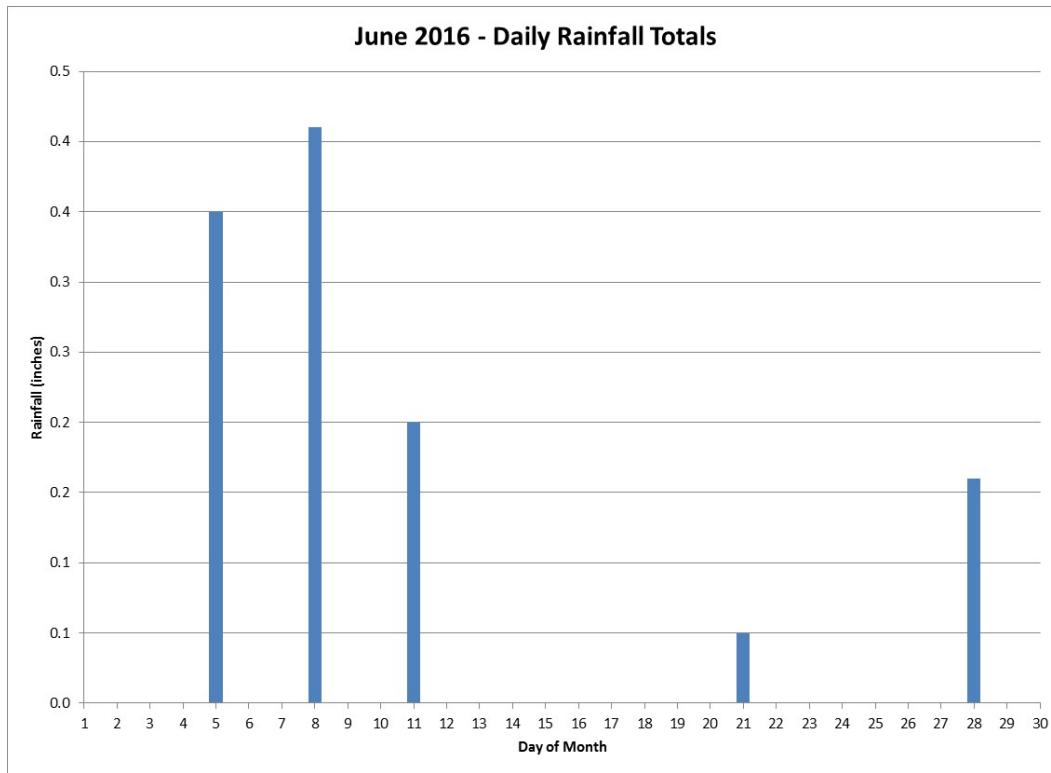


Figure 50 Daily Rainfall for the Month of June 2016

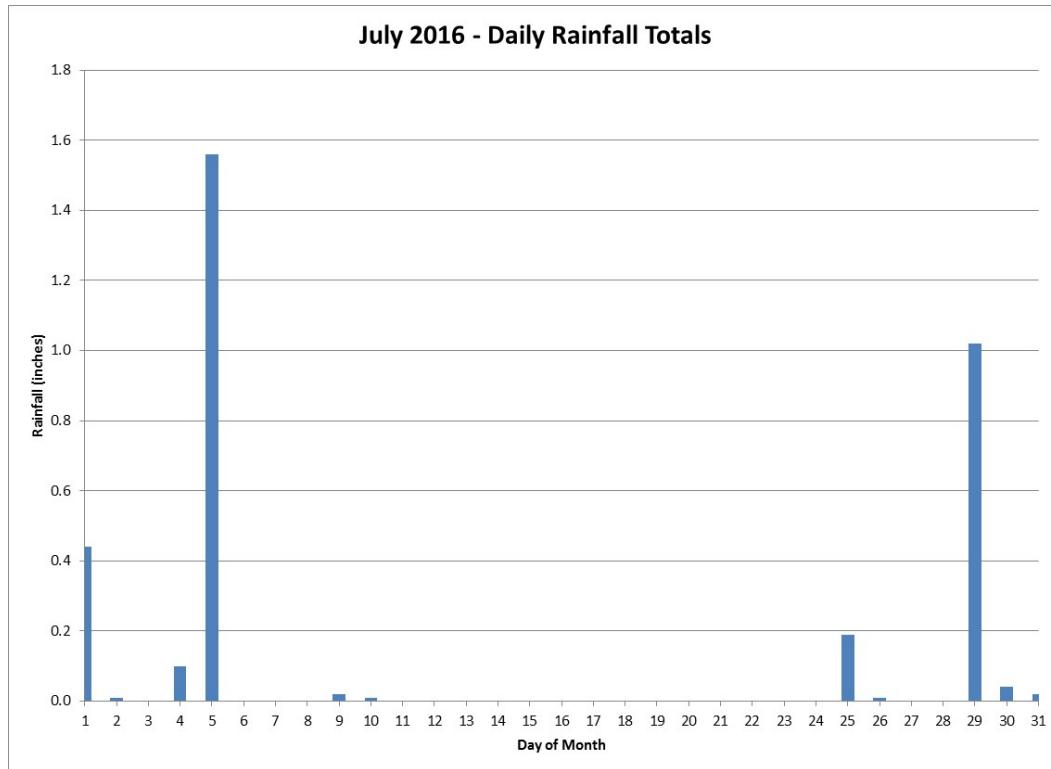


Figure 51 Daily Rainfall for the Month of July 2016

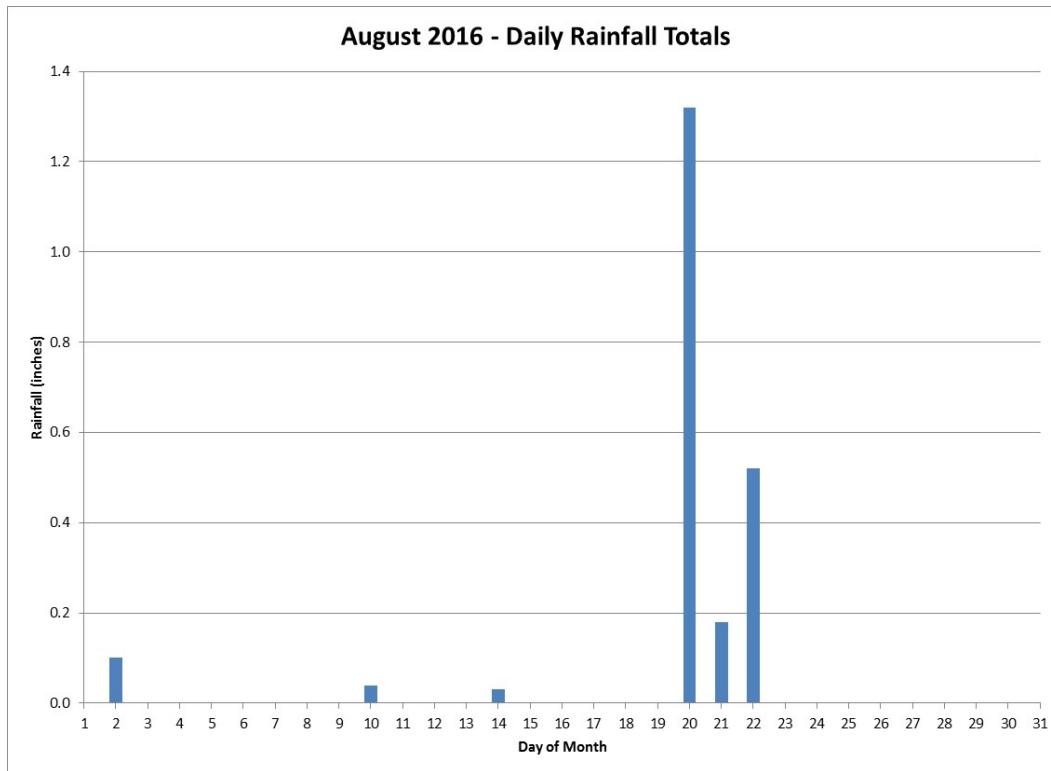


Figure 52 Daily Rainfall for the Month of August 2016

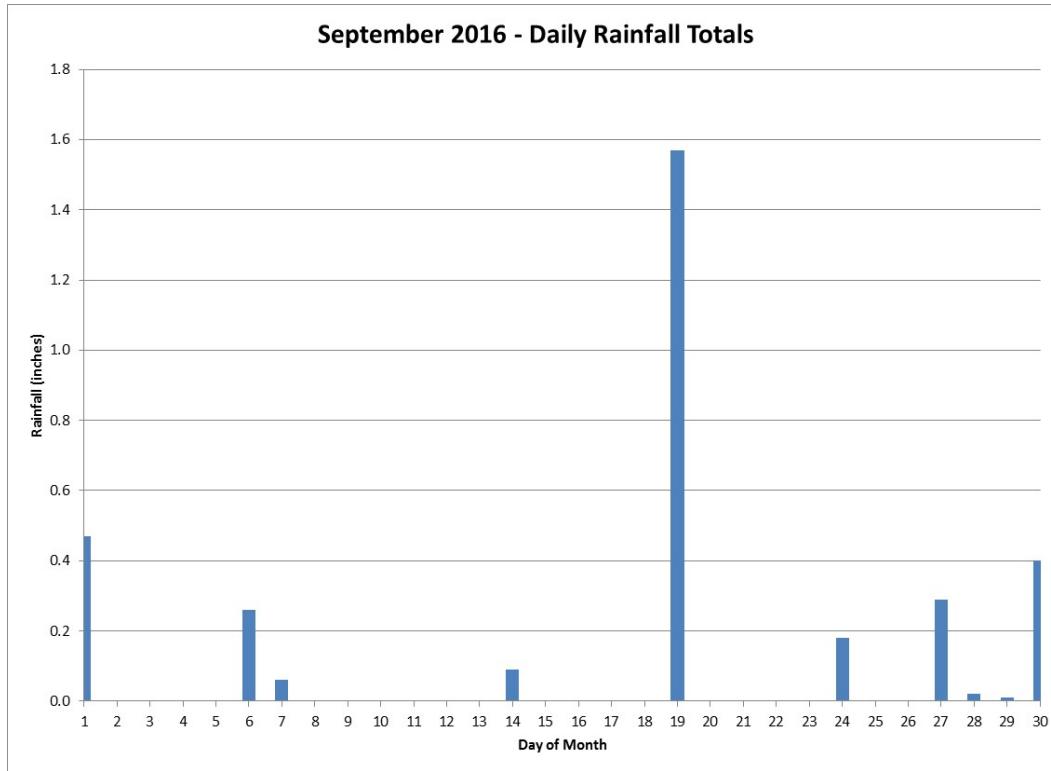


Figure 53 Daily Rainfall for the Month of September 2016

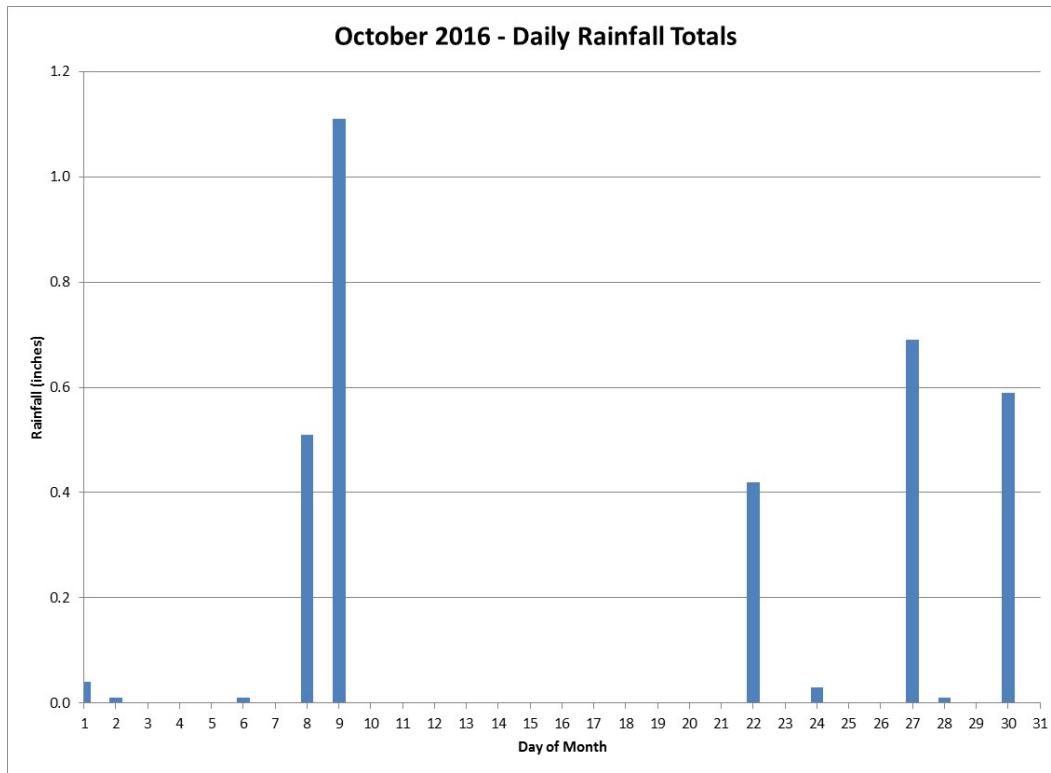


Figure 54 Daily Rainfall for the Month of October 2016

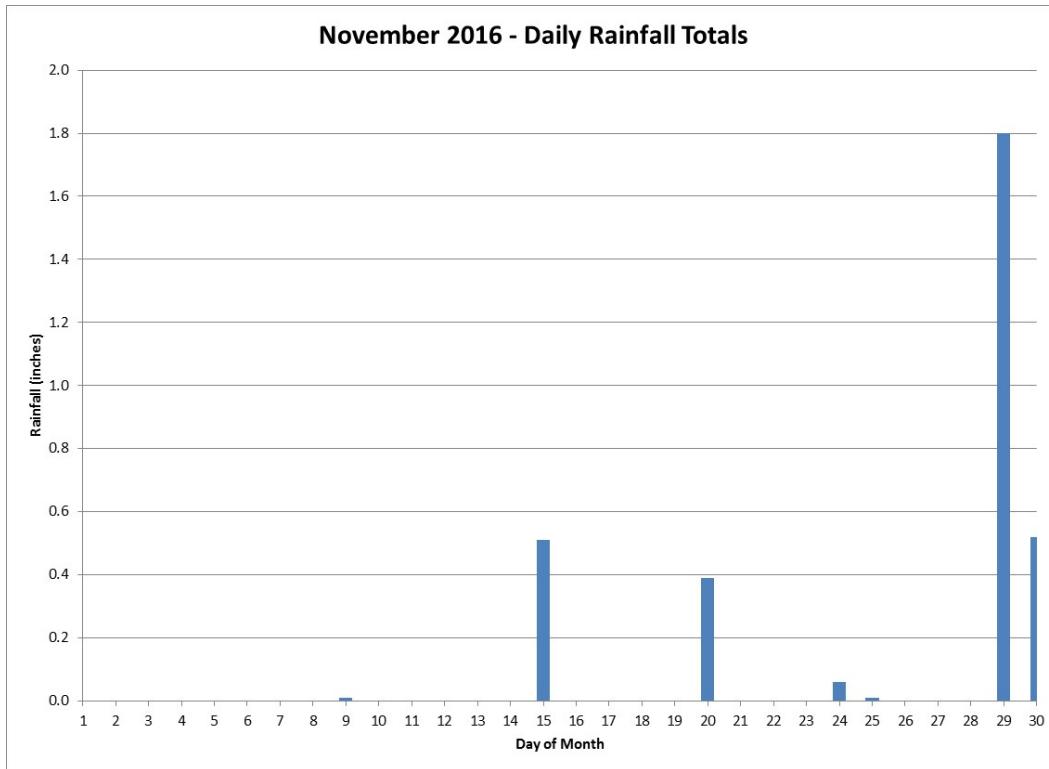


Figure 55 Daily Rainfall for the Month of November 2016

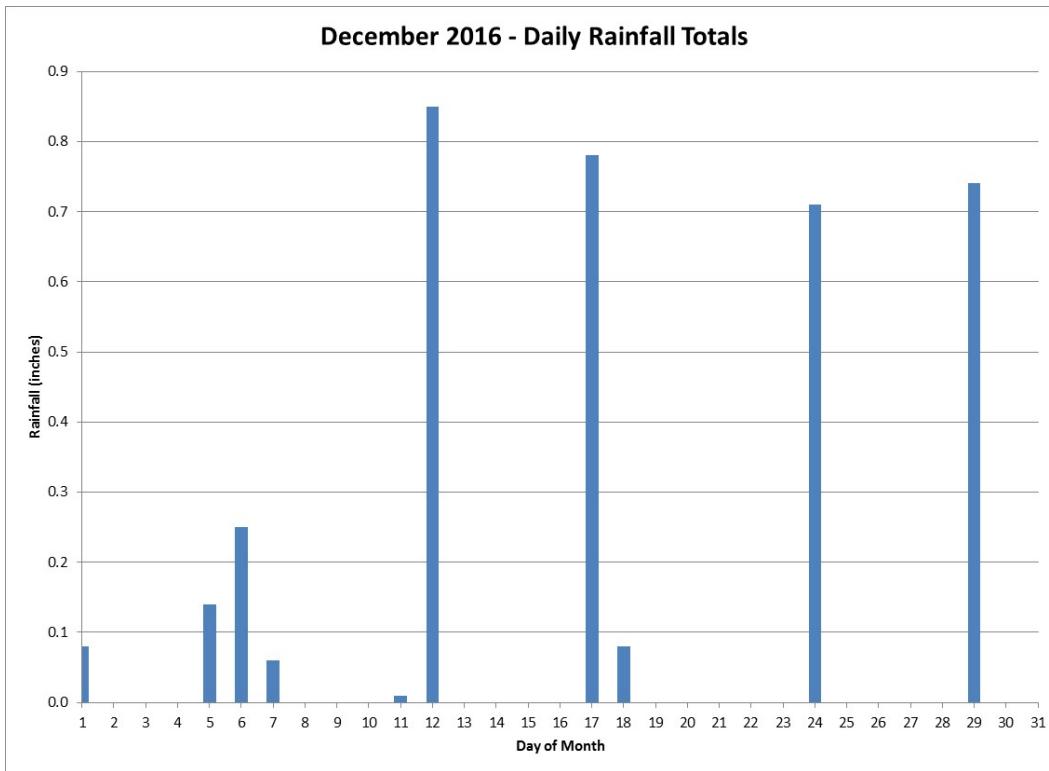


Figure 56 Daily Rainfall for the Month of December 2016

Table 6. Historic Monthly Precipitation for Brookhaven National Laboratory from 1949 to present (@ 2 meters)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1949	5.55	4.71	2.88	3.63	3.32	Trace	3.07	5.21	3.49	1.74	2.96	3.36	39.92
1950	2.80	4.28	3.98	2.41	5.23	2.72	3.22	4.26	1.38	1.69	4.34	4.36	40.67
1951	3.75	4.99	5.02	3.42	3.68	2.64	2.08	4.50	1.06	5.48	6.01	6.17	48.80
1952	7.10	3.54	5.44	3.61	7.64	2.78	1.00	7.61	1.35	0.31	3.56	4.45	48.39
1953	6.73	4.16	10.36	5.59	3.34	1.66	2.76	2.40	0.90	3.17	5.03	6.43	52.53
1954	2.74	2.18	4.21	5.36	4.08	1.69	0.94	11.98	10.47	2.44	5.42	6.39	57.90
1955	0.62	3.26	4.79	4.28	0.95	2.53	1.65	9.04	3.96	11.43	7.19	0.82	50.52
1956	3.52	6.32	5.47	2.97	2.63	3.00	5.79	1.50	3.64	2.95	4.63	6.03	48.45
1957	2.36	2.53	3.20	4.44	1.46	0.42	2.84	4.25	3.57	3.86	4.41	8.45	41.79
1958	7.96	4.58	6.65	6.34	5.81	2.28	3.42	5.37	4.24	7.39	2.88	2.68	59.60
1959	2.60	2.06	6.71	3.93	1.75	5.35	6.85	3.72	1.36	3.13	4.46	5.12	47.04
1960	3.59	5.48	3.38	3.27	2.54	2.13	6.03	1.79	7.49	3.94	2.62	4.31	46.57
1961	3.56	4.10	4.60	5.70	6.17	2.30	5.61	4.23	6.23	3.06	2.89	3.70	52.15
1962	4.38	5.77	3.63	3.31	1.12	3.55	1.64	7.64	4.07	4.62	5.04	2.83	47.60
1963	3.27	3.88	4.27	2.56	3.08	5.51	2.65	2.10	3.66	0.18	6.89	2.78	40.83
1964	5.89	4.76	3.56	8.37	0.63	1.41	4.40	1.16	3.02	4.29	3.07	6.63	47.19
1965	4.88	3.03	2.74	4.20	1.63	1.69	3.43	5.15	1.51	2.15	1.83	2.11	34.35
1966	4.57	5.18	1.73	2.13	6.55	1.40	1.12	3.23	6.53	4.45	2.89	4.15	43.93
1967	1.65	3.98	8.18	4.14	7.98	5.30	6.01	5.43	2.24	2.11	4.00	7.60	58.62
1968	3.00	2.21	7.54	2.00	4.95	4.24	0.50	3.10	2.08	3.01	8.09	8.22	48.94
1969	1.04	4.03	3.62	5.15	2.44	2.06	8.62	5.51	3.60	3.69	4.48	7.83	52.07
1970	0.81	4.37	5.44	4.57	3.44	1.77	3.10	6.08	2.42	1.41	6.52	3.73	43.66
1971	2.95	6.45	3.55	3.30	3.80	0.92	5.03	3.86	2.12	3.41	6.86	2.57	44.82
1972	2.41	6.12	5.40	4.53	6.10	7.30	1.03	1.29	3.08	7.64	7.51	6.22	58.63
1973	4.44	4.36	4.38	7.77	5.46	3.25	4.45	3.11	2.51	2.79	2.22	8.00	52.74
1974	4.96	2.82	5.06	3.49	3.13	2.50	0.81	2.55	5.10	2.66	1.94	6.78	41.80
1975	6.50	4.06	4.27	3.89	3.45	5.37	3.33	2.01	5.58	3.61	5.89	4.92	52.88
1976	5.98	3.57	3.30	2.27	3.89	3.27	4.32	7.57	2.07	5.42	0.54	2.96	45.16

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	3.09	2.46	5.47	4.28	2.04	4.31	1.51	5.49	5.73	6.12	6.39	6.93	53.82
1978	10.72	2.60	3.33	2.39	6.47	0.81	4.63	5.22	4.26	4.11	2.79	6.12	53.45
1979	13.01	5.27	3.53	4.96	4.09	2.15	0.61	7.76	3.20	4.57	3.95	3.02	56.12
1980	2.02	1.18	7.20	6.16	1.52	3.60	1.92	1.56	0.98	3.59	4.20	1.06	34.99
1981	1.15	5.16	1.80	4.59	2.17	3.14	2.69	0.96	5.17	4.49	3.16	5.55	40.03
1982	7.20	2.90	3.38	5.44	1.71	12.85	1.77	3.45	1.40	2.07	3.87	2.38	48.42
1983	4.07	4.36	8.68	11.09	4.22	2.63	4.20	4.48	2.09	3.67	8.68	5.67	63.84
1984	2.87	6.38	6.92	5.41	8.08	6.68	7.06	1.02	4.16	3.20	2.40	2.98	57.16
1985	1.07	1.82	2.62	1.56	4.87	6.38	2.30	4.89	1.54	1.53	6.85	1.10	36.53
1986	3.96	3.46	3.17	2.35	1.09	1.66	5.02	5.69	0.86	2.25	6.72	7.50	43.73
1987	6.74	1.21	5.95	4.32	1.83	1.86	1.48	4.38	4.05	2.22	3.55	3.20	40.79
1988	3.59	4.81	4.22	2.17	2.58	1.43	3.93	1.36	3.52	3.87	9.05	2.52	43.05
1989	2.23	4.09	5.20	4.66	10.47	7.24	5.84	9.17	4.45	8.90	5.16	1.25	68.66
1990	5.24	2.92	2.14	4.96	6.52	3.95	2.64	6.75	3.04	7.17	1.78	5.90	53.01
1991	4.41	1.86	5.45	4.30	2.78	1.87	2.11	9.19	4.45	2.61	1.80	4.30	45.13
1992	2.40	2.18	3.34	1.78	3.05	4.90	4.76	5.61	3.51	1.07	5.96	6.60	45.16
1993	2.47	4.10	7.11	3.81	1.71	1.37	1.84	1.61	4.36	4.69	3.72	6.11	42.90
1994	5.78	4.04	6.55	2.26	2.93	0.51	0.91	5.04	4.41	1.09	6.34	4.30	44.16
1995	2.93	3.74	1.53	2.52	2.79	3.12	1.78	0.54	4.91	5.97	5.83	3.74	39.40
1996	5.22	3.51	3.58	6.40	3.39	4.41	4.94	2.68	6.08	8.24	3.11	8.66	60.22
1997	3.82	2.64	5.10	4.21	2.67	2.16	2.21	3.33	1.27	2.55	5.42	4.66	40.04
1998	7.01	5.66	8.08	6.55	8.58	8.43	0.94	3.68	2.50	1.91	2.05	1.22	56.61
1999	8.85	4.81	5.32	2.35	2.41	1.04	2.12	8.71	5.90	4.78	2.58	2.85	51.72
2000	3.75	2.58	5.49	6.29	4.28	5.18	8.37	3.38	6.86	0.31	3.79	4.09	54.37
2001	3.28	2.63	10.37	2.03	4.22	6.46	3.47	4.68	4.04	1.04	0.74	2.59	45.55
2002	3.07	1.16	5.05	4.58	4.48	4.37	1.37	3.94	5.84	6.40	6.18	5.63	52.07
2003	2.48	5.74	5.99	5.11	6.07	12.28	2.38	5.19	5.22	4.80	3.63	4.22	63.11
2004	2.15	3.14	3.47	4.94	2.59	1.34	3.05	4.30	5.14	1.62	2.16	1.96	35.86
2005	3.32	2.10	2.47	2.53	2.36	1.48	2.16	0.87	1.09	22.14	5.00	4.60	50.12
2006	5.52	2.87	0.89	7.17	6.73	6.73	5.73	6.44	3.21	7.22	6.61	2.47	61.59

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2007	4.32	2.00	5.58	6.87	2.06	3.18	7.58	2.78	1.69	1.71	3.31	4.25	45.33
2008	2.36	5.84	5.90	4.04	3.66	2.28	1.97	3.07	9.31	4.02	3.82	4.37	50.64
2009	1.27	1.74	1.79	5.39	6.05	7.99	7.19	1.15	3.18	6.13	4.65	7.64	54.17
2010	2.15	6.01	11.98	0.74	3.88	1.64	6.70	2.21	4.56	3.08	2.91	4.08	49.94
2011	3.23	3.61	3.00	4.34	3.37	4.33	2.34	9.81	4.74	5.75	3.52	3.16	51.20
2012	3.01	1.27	1.11	3.81	4.53	7.74	8.26	4.57	3.49	3.24	2.49	7.30	50.82
2013	2.35	5.84	3.82	1.67	3.04	8.37	4.14	2.05	2.39	0.26	3.13	6.17	43.23
2014	2.90	5.63	6.73	4.86	4.82	2.35	2.58	3.67	2.66	5.23	5.79	7.03	54.25
2015	5.15	2.98	5.87	1.81	0.53	4.38	1.69	1.54	3.53	4.23	2.41	5.25	39.37
2016	3.08	5.40	3.41	2.65	3.84	1.17	3.42	2.19	3.35	3.42	3.30	3.70	38.93
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Average	4.01	3.80	4.79	4.18	3.83	3.68	3.46	4.27	3.69	4.02	4.31	4.64	48.63
Max	13.01	6.45	11.98	11.09	10.47	12.85	8.62	11.98	10.47	22.14	9.05	8.66	68.66
Min	0.62	1.16	0.89	0.74	0.53	0.42	0.50	0.54	0.86	0.18	0.54	0.82	34.35

Min

Max

Wind Direction and Wind Speed

Wind speed and direction are recorded via R.M. Young 5106 marine grade mechanical wind sensor. This unit has a 0 to 100 m/s wind speed range and has been modified to have a 0.5 m/s wind speed threshold sensitivity. Accuracy is ± 0.3 m/s. The direction sensor has a 355° electrical range and 360° mechanical. Direction accuracy is $\pm 3^\circ$ and sensitivity is 1.1 m/s (wind speed needed for accurate measurement). These units require a wind tunnel calibration and are sent out for calibration on an annual basis. Enough spare units are stocked to allow change out without data loss.

Average daily wind speed recorded at the 10-meter and 85-meter locations is given in Figure 57. Historic (Figures 58-59), Annual (Figures 60-62) and Monthly (Figures 63-95) wind roses are presented in Figures 58 through 95. A wind rose is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location. The wind rose data used in the plots are generated from hourly averages. Wind roses are presented for the 10-, 50- and 85-meter locations. Speed bins are 0.3 to 2.5 m/s, 2.5 to 5m/s, 5 to 7.5 m/s, 7.5 to 10 m/s and >10 m/s. Percent calm data (<0.3 m/s) and percent bad data are also listed. Prevailing winds at BNL are from the south-southwest with a secondary west-northwest component at the 85 meter level and west-northwest with a secondary south-southwest component at the 10 meter level.

Figures 96 through 119 present the 1-minute data for wind speed and wind gust. Plots contain data from 10-, 50- and 85-meters.

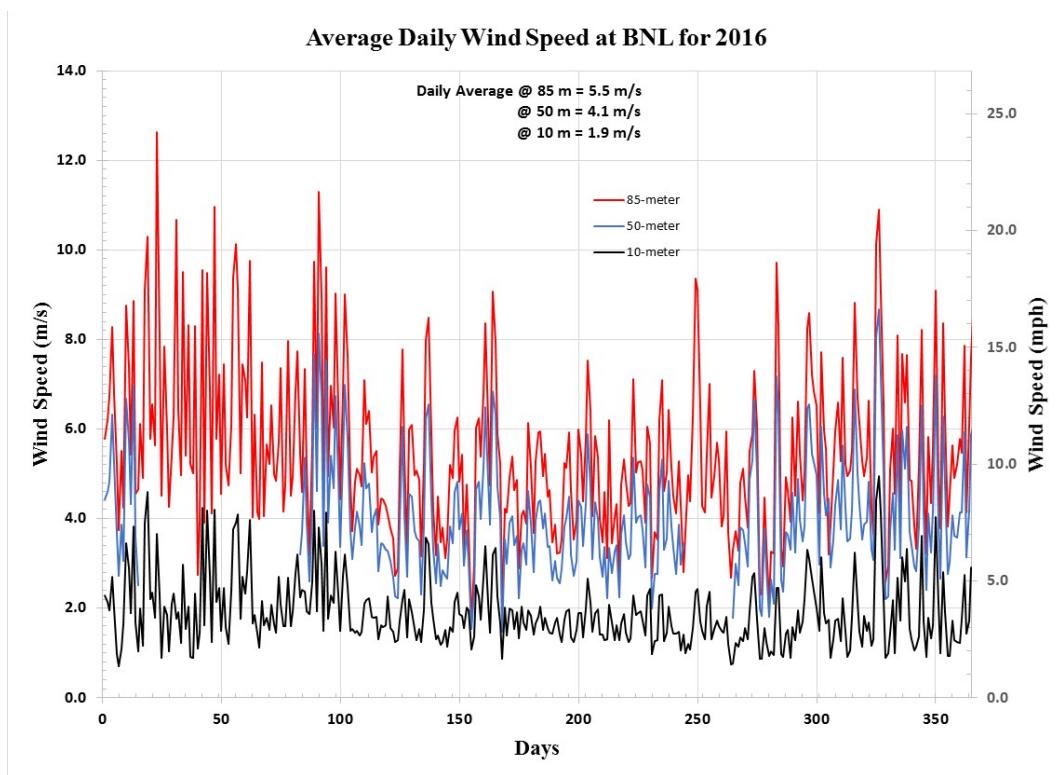


Figure 57 Average Daily Wind Speed (m/s) at the 10-meter, 50-meter and 85-meter heights
at Brookhaven National Laboratory for 2016

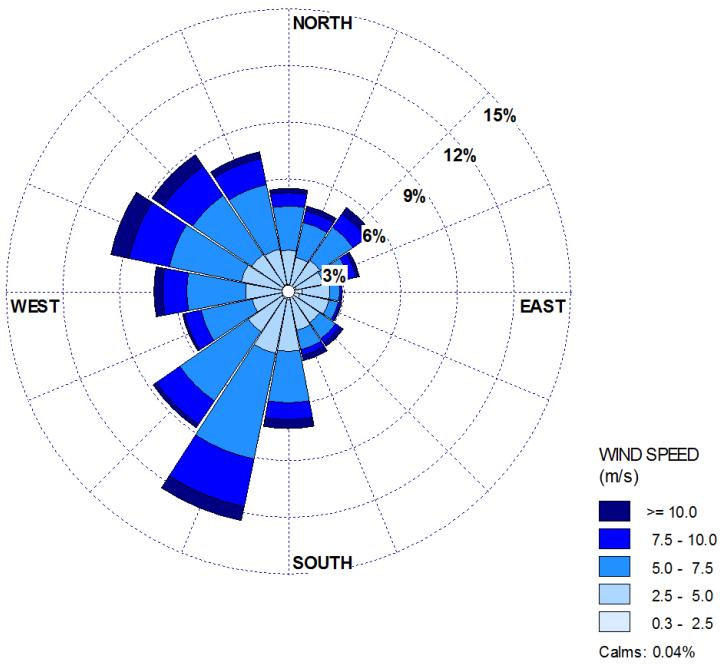


Figure 58 Historic Annual One-hour Wind Roses for the Years 1994 to 2016 from the 85m level

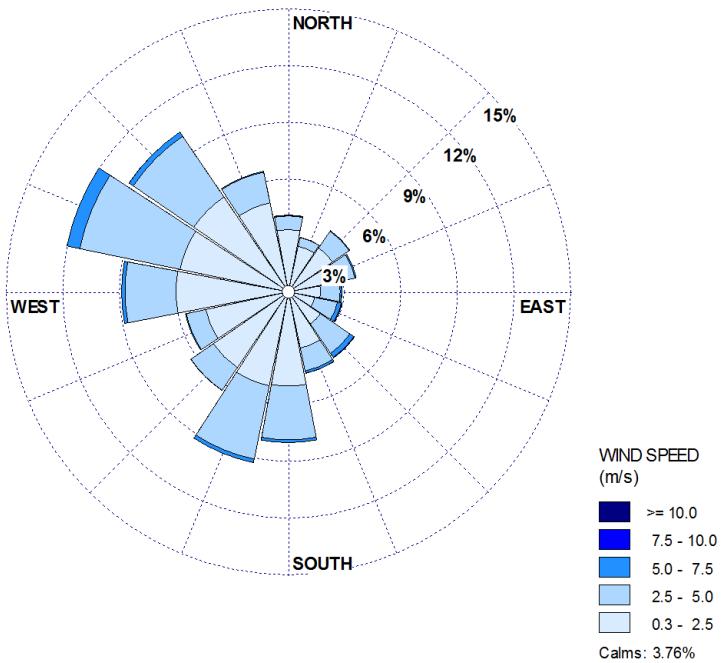


Figure 59 Historic Annual One-hour Wind Roses for the Years 1994 to 2016 from the 10m level

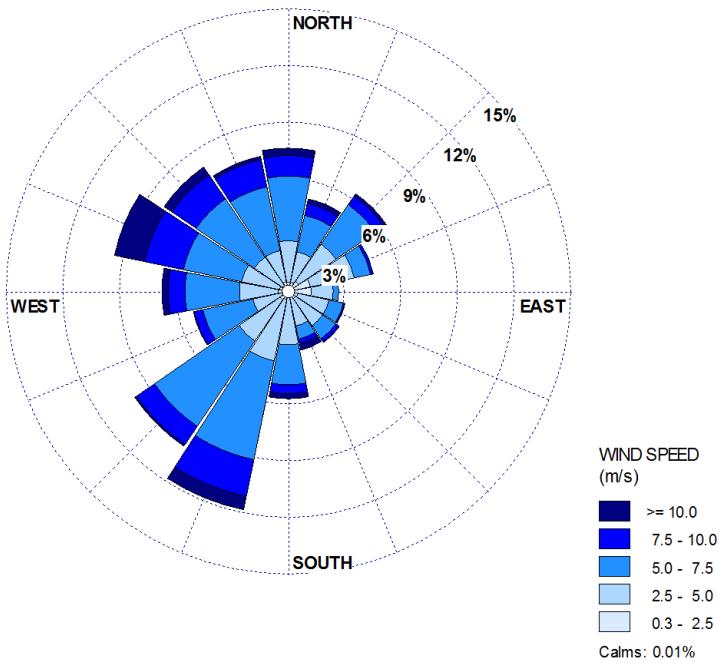


Figure 60 Annual One-hour Wind Roses for the Year 2016 from the 85m level

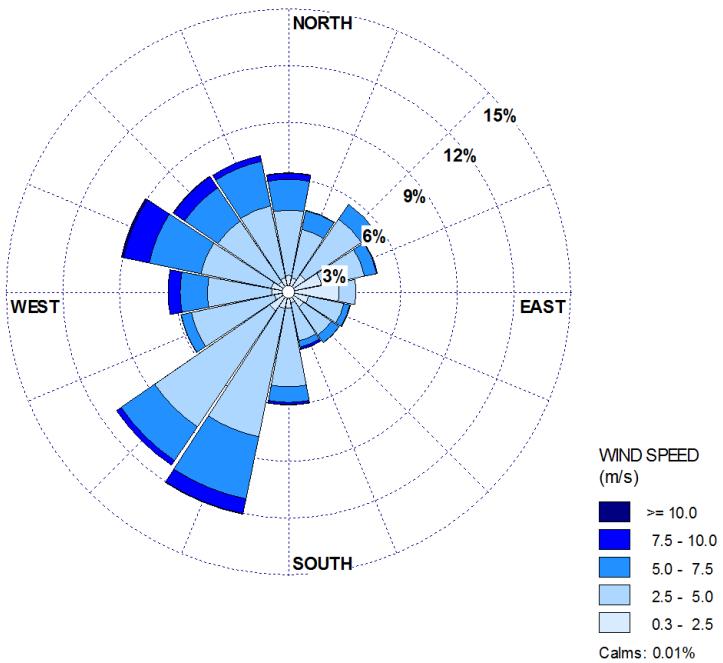


Figure 61 Annual One-hour Wind Roses for the Year 2016 from the 50m level

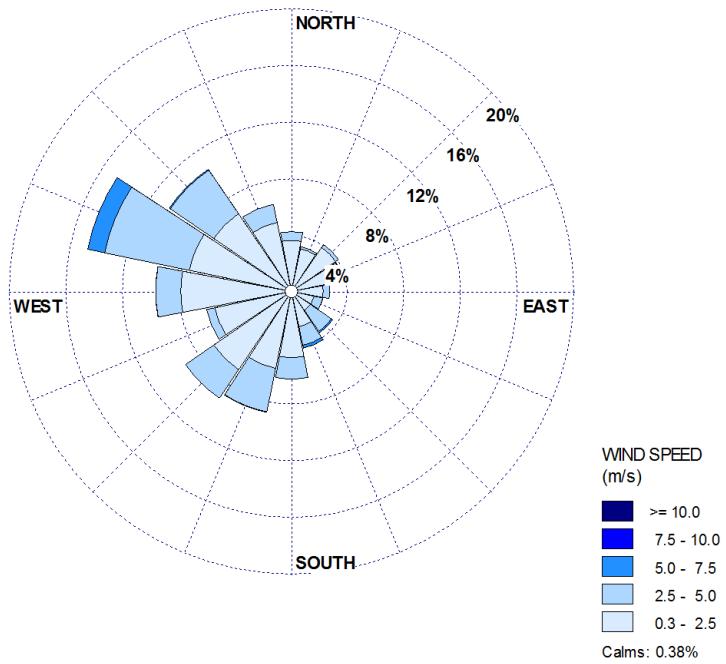


Figure 62 Annual One-hour Wind Roses for the Year 2016 from the 10m level

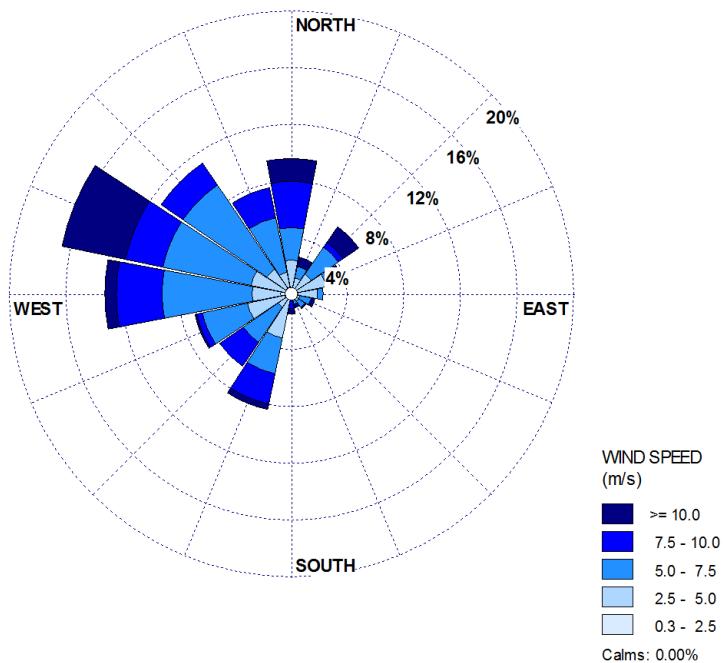


Figure 63 One-hour Wind Roses for the Month of January 2016 from the 85m level

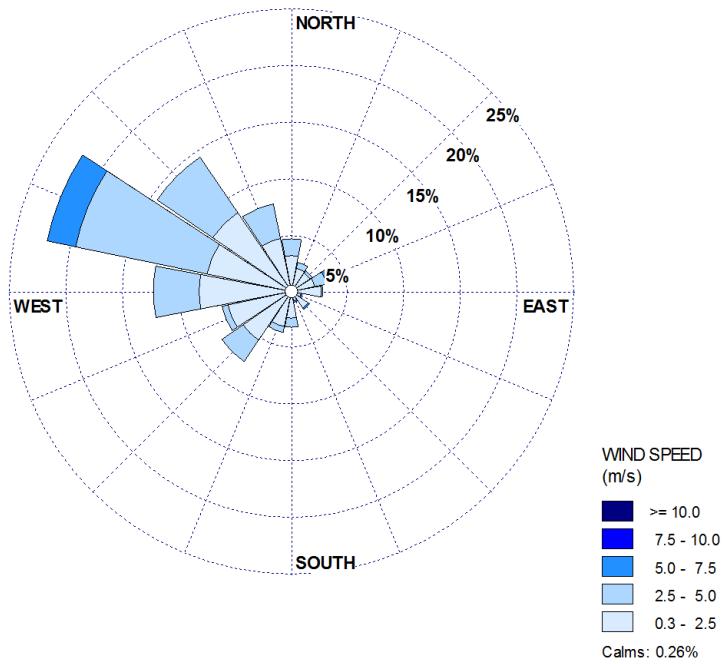


Figure 64 One-hour Wind Roses for the Month of January 2016 from the 10m level

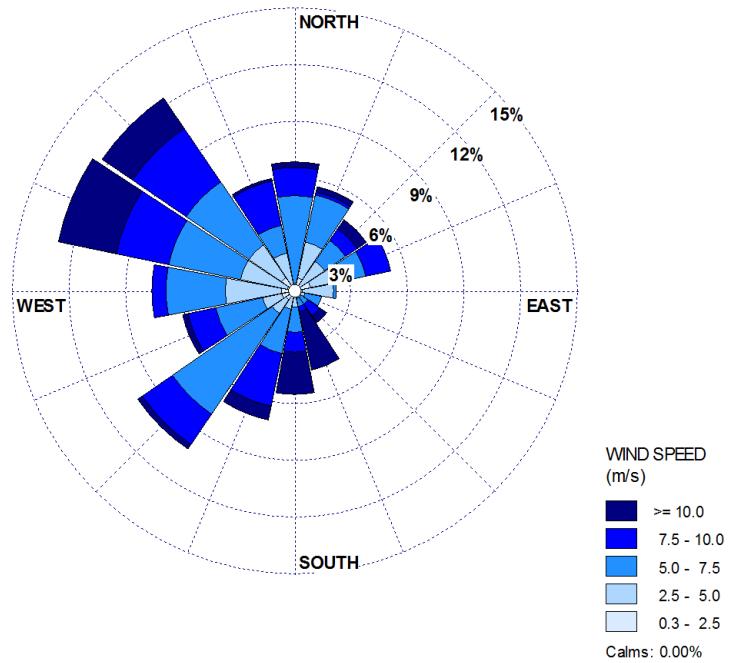


Figure 65 One-hour Wind Roses for the Month of February 2016 from the 85m level

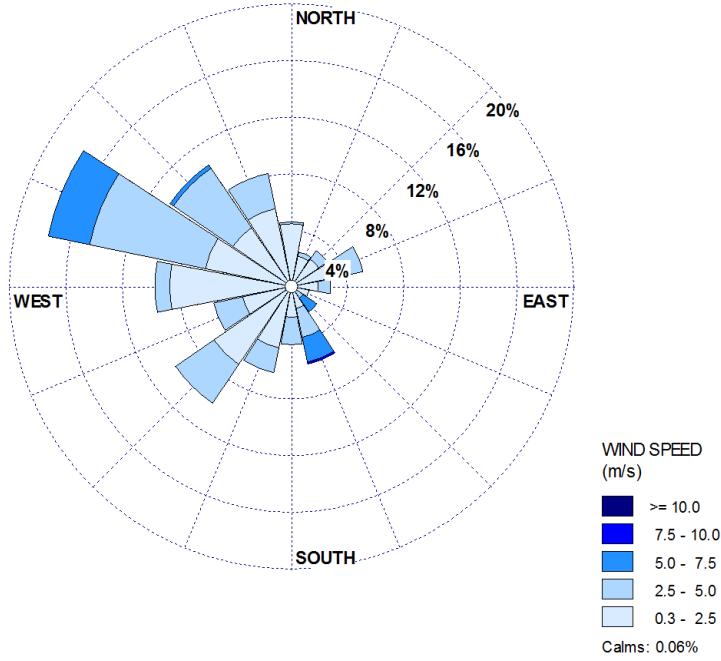


Figure 66 One-hour Wind Roses for the Month of February 2016 from the 10m level

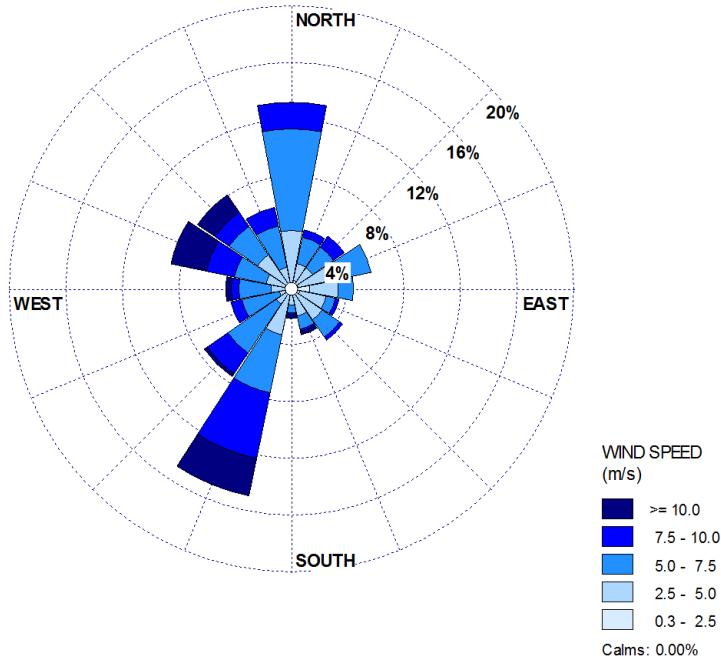


Figure 67 One-hour Wind Roses for the Month of March 2016 from the 85m level

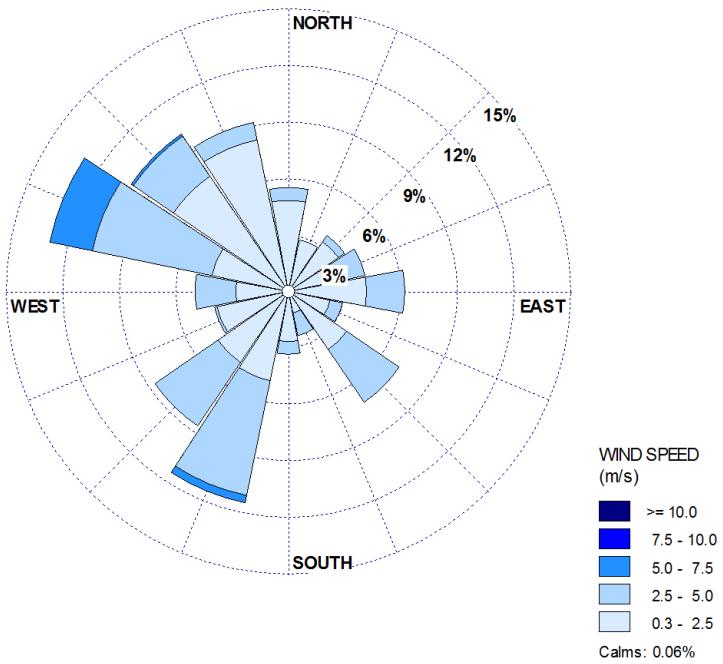


Figure 68 One-hour Wind Roses for the Month of March 2016 from the 10m level

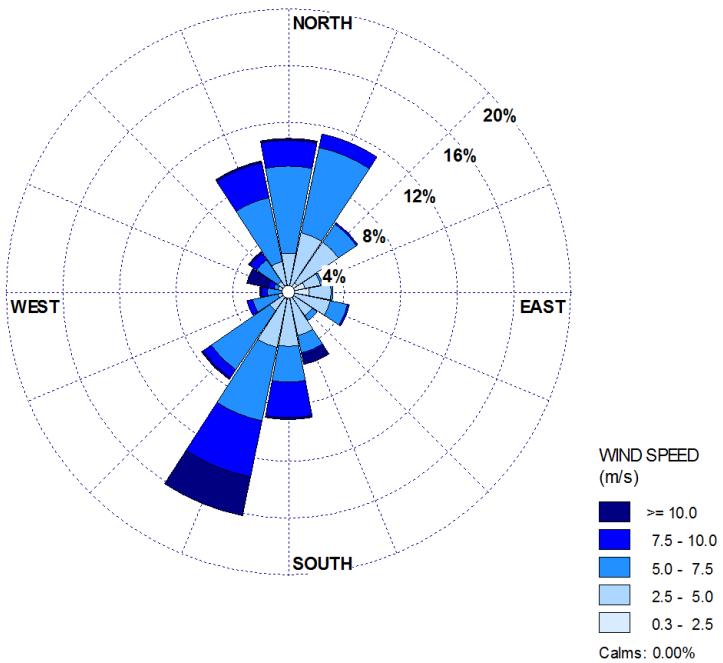


Figure 69 One-hour Wind Roses for the Month of April 2016 from the 85m level

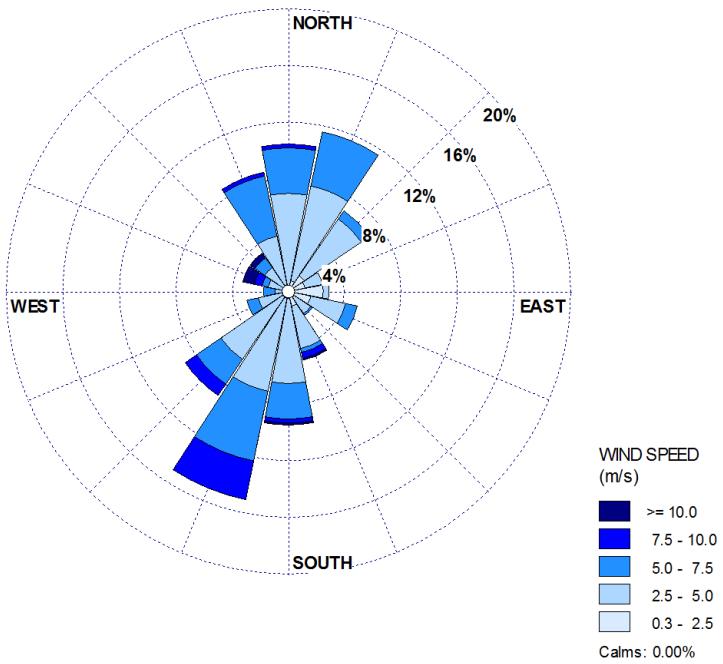


Figure 70 One-hour Wind Roses for the Month of April 2016 from the 50m level

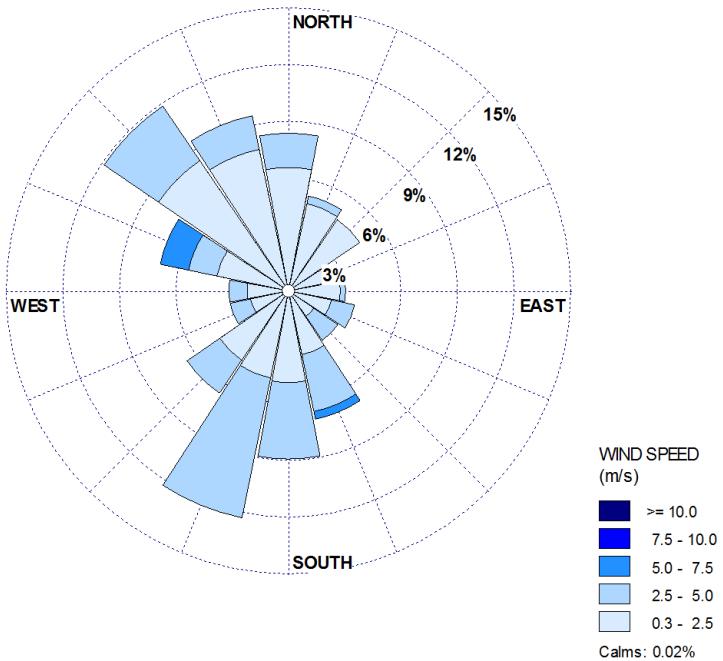


Figure 71 One-hour Wind Roses for the Month of April 2016 from the 10m level

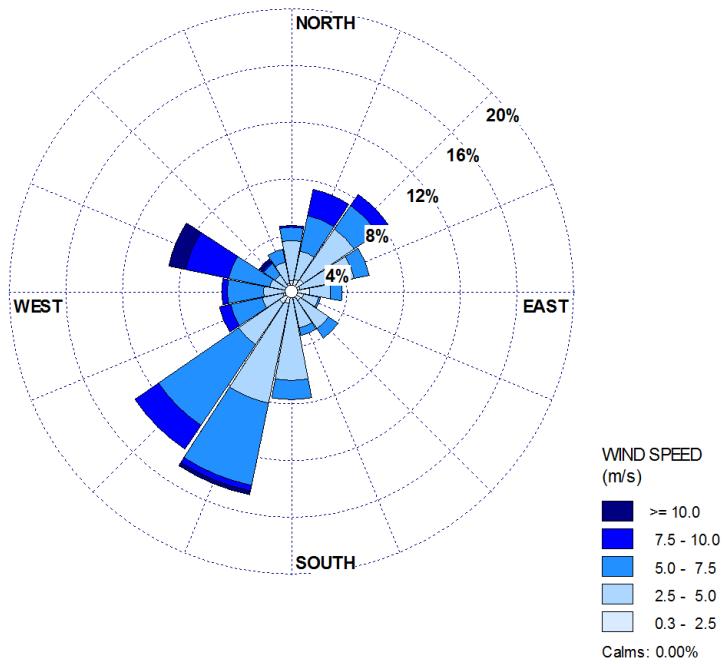


Figure 72 One-hour Wind Roses for the Month of May 2016 from the 85m level

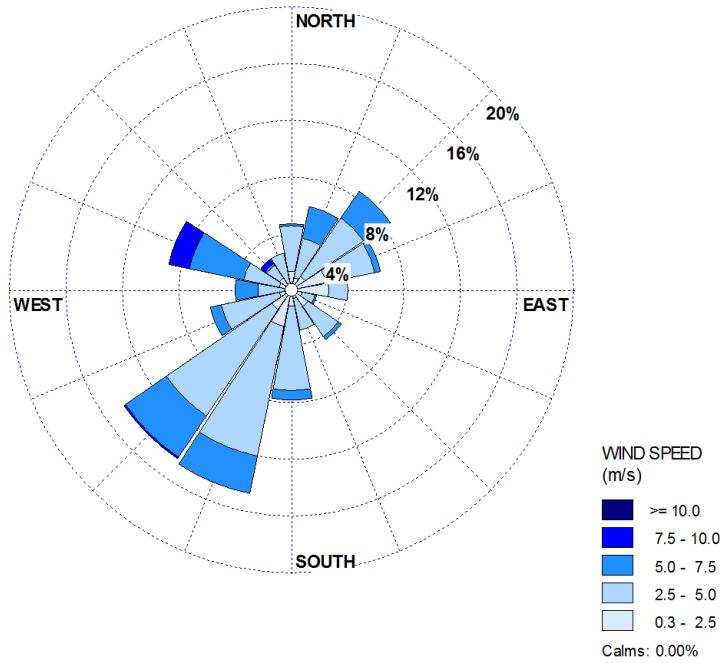


Figure 73 One-hour Wind Roses for the Month of May 2016 from the 50m level

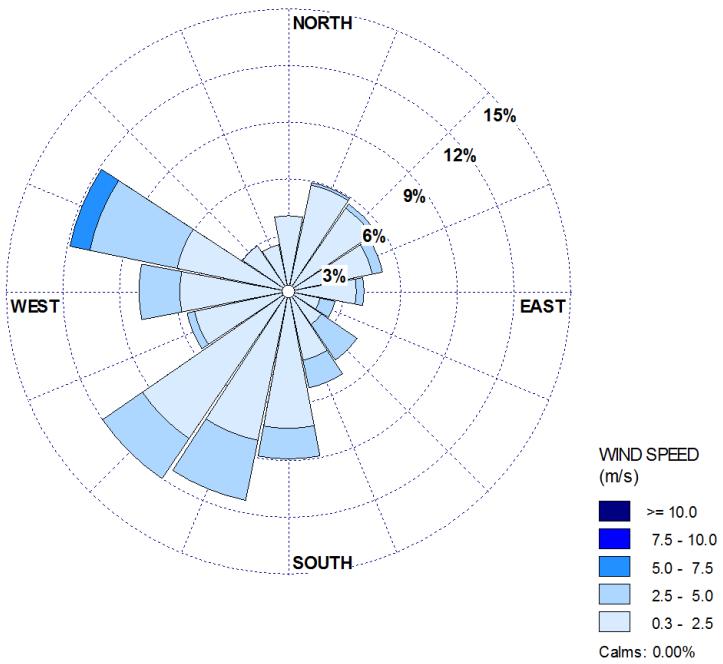


Figure 74 One-hour Wind Roses for the Month of May 2016 from the 10m level

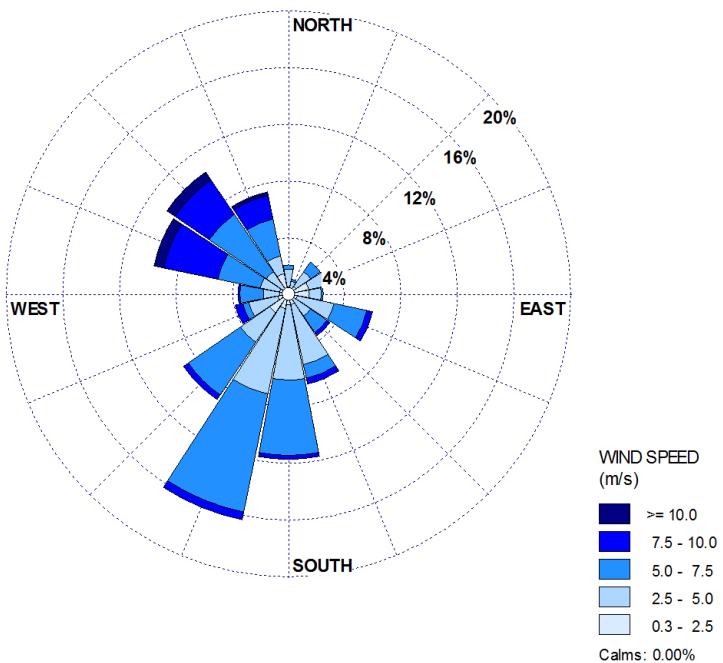


Figure 75 One-hour Wind Roses for the Month of June 2016 from the 85m level

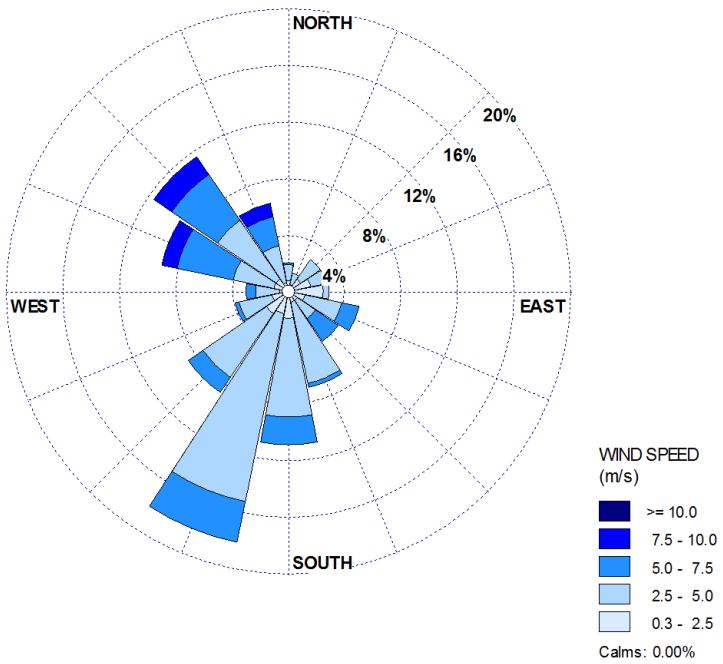


Figure 76 One-hour Wind Roses for the Month of June 2016 from the 50m level

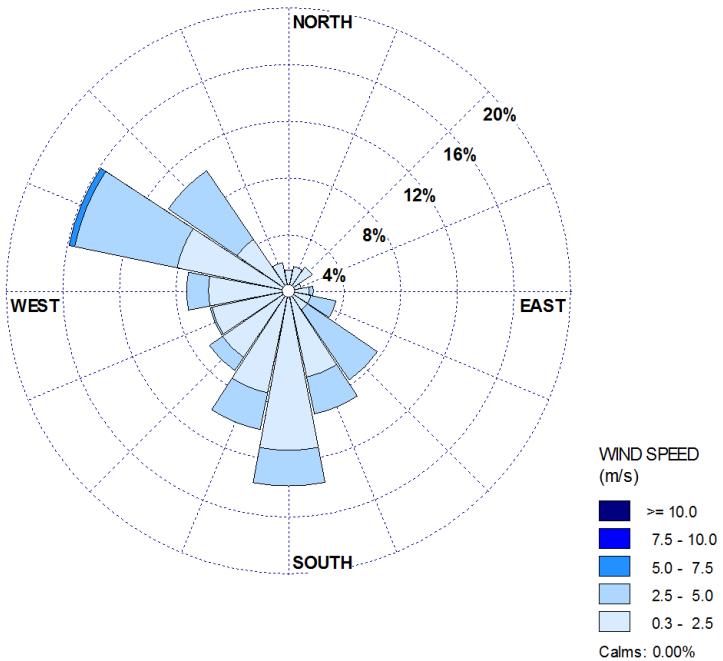


Figure 77 One-hour Wind Roses for the Month of June 2016 from the 10m level

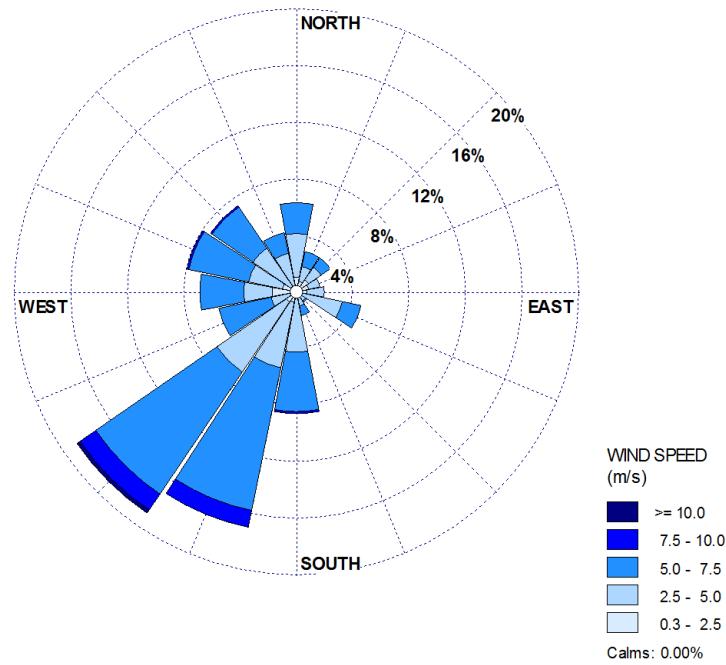


Figure 78 One-hour Wind Roses for the Month of July 2016 from the 85m level

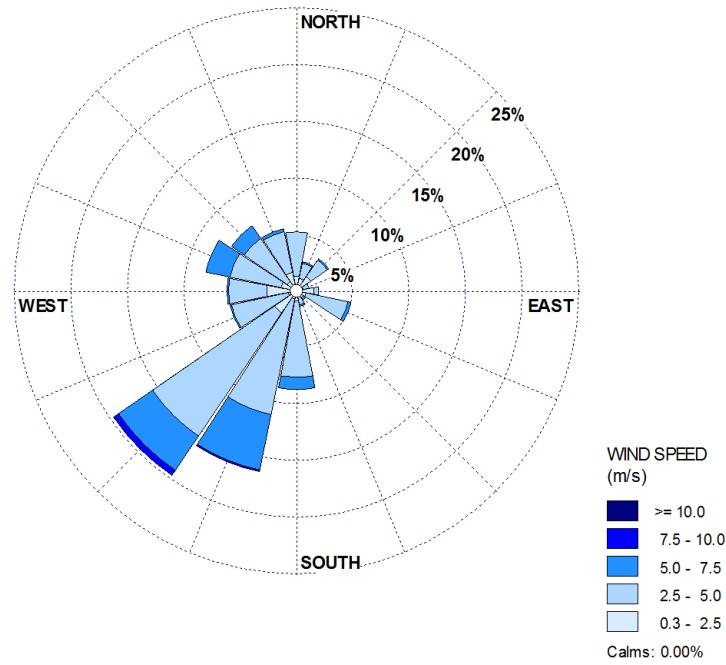


Figure 79 One-hour Wind Roses for the Month of July 2016 from the 50m level

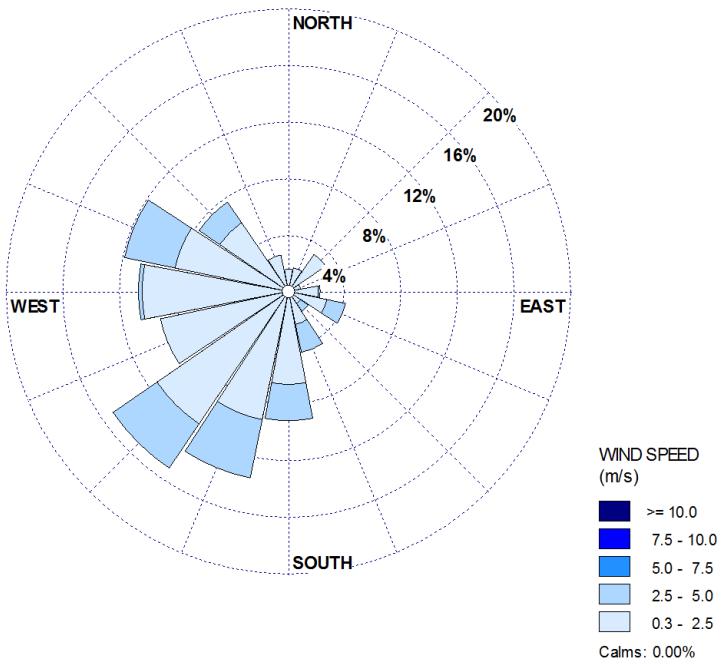


Figure 80 One-hour Wind Roses for the Month of July 2016 from the 10m level

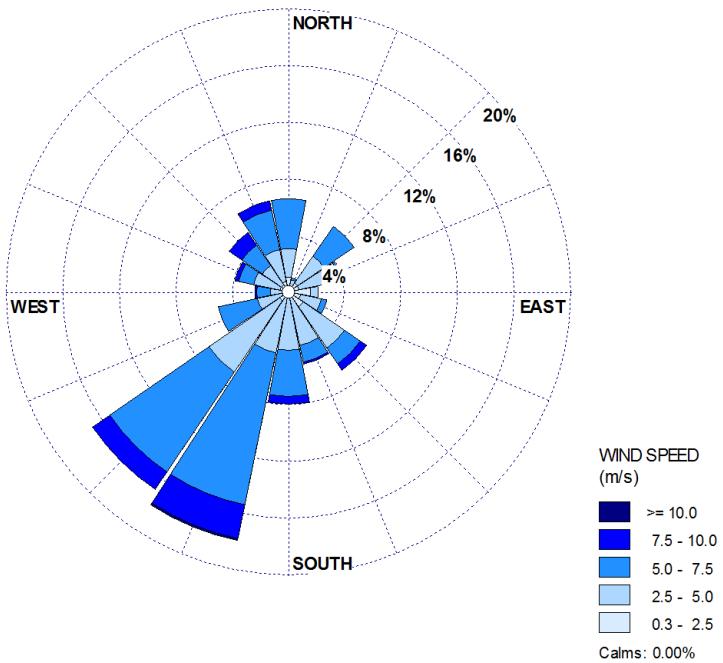


Figure 81 One-hour Wind Roses for the Month of August 2016 from the 85m level

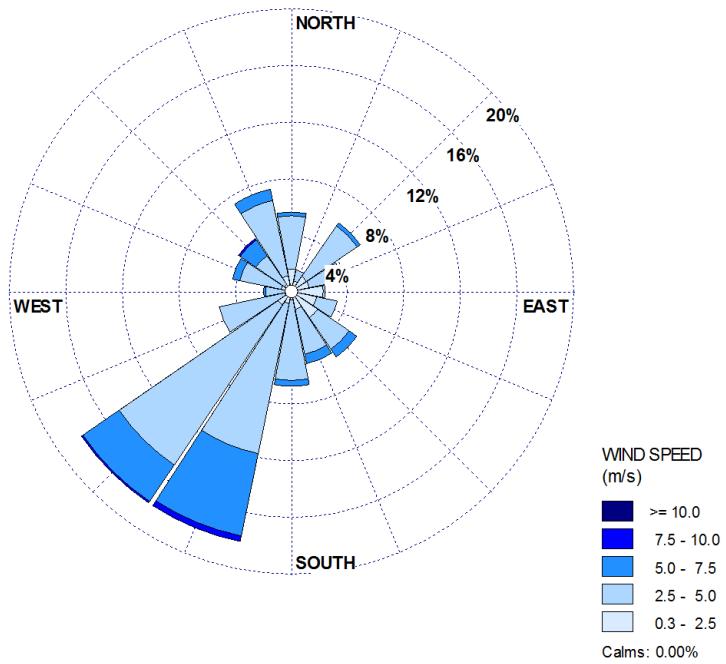


Figure 82 One-hour Wind Roses for the Month of August 2016 from the 50m level

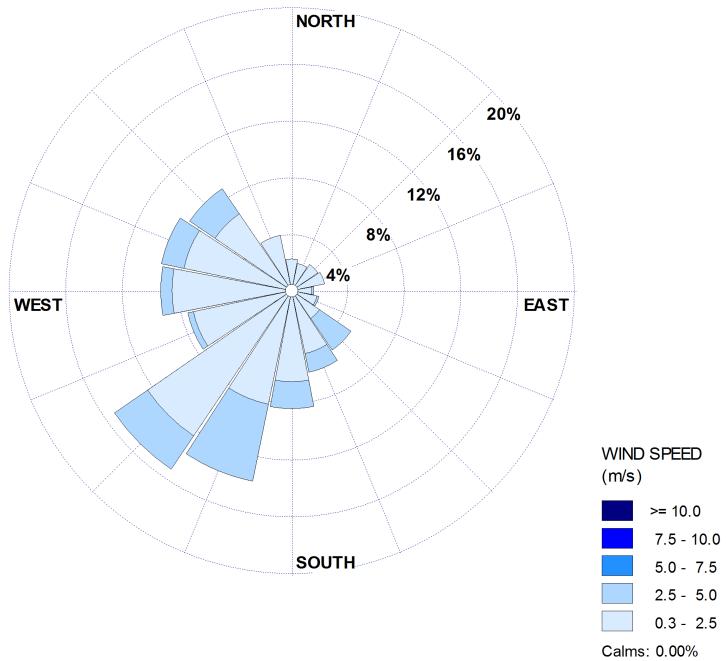


Figure 83 One-hour Wind Roses for the Month of August 2016 from the 10m level

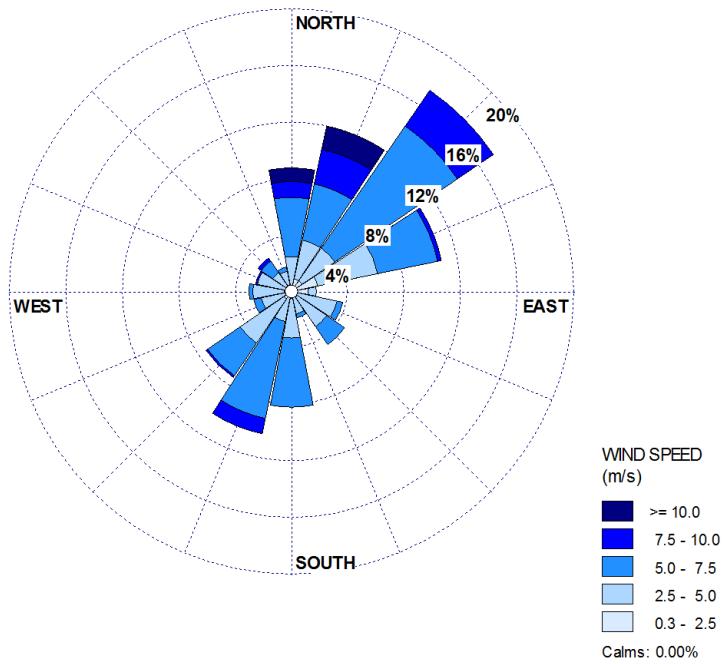


Figure 84 One-hour Wind Roses for the Month of September 2016 from the 85m level

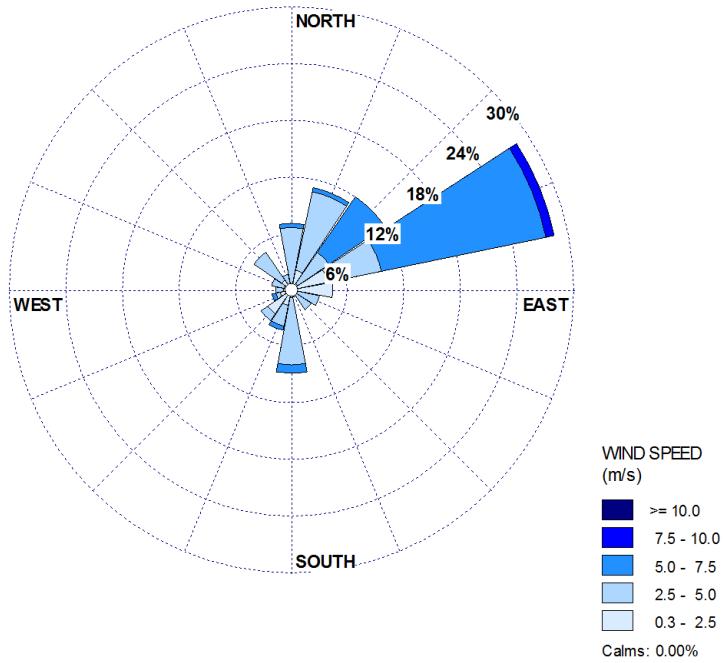


Figure 85 One-hour Wind Roses for the Month of September 2016 from the 50m level (station out of service 9-1 thru 9-20)

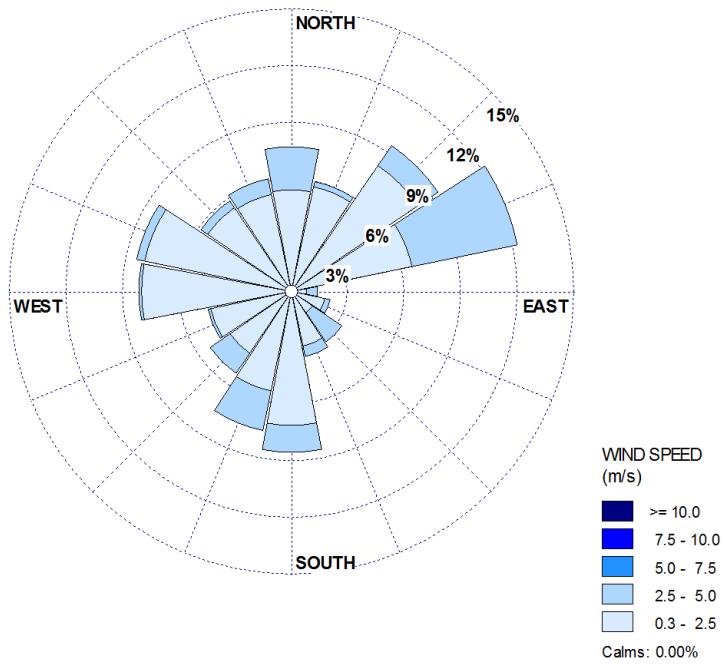


Figure 86 One-hour Wind Roses for the Month of September 2016 from the 10m level

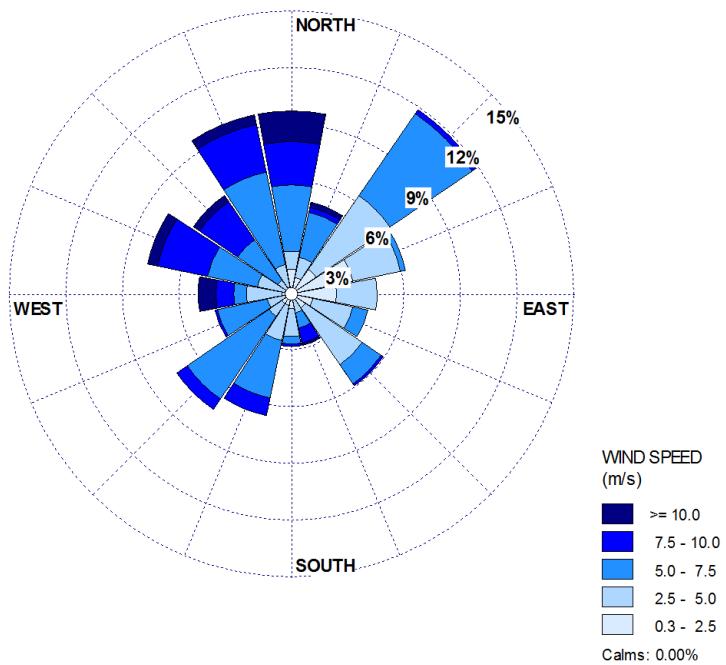


Figure 87 One-hour Wind Roses for the Month of October 2016 from the 85m level

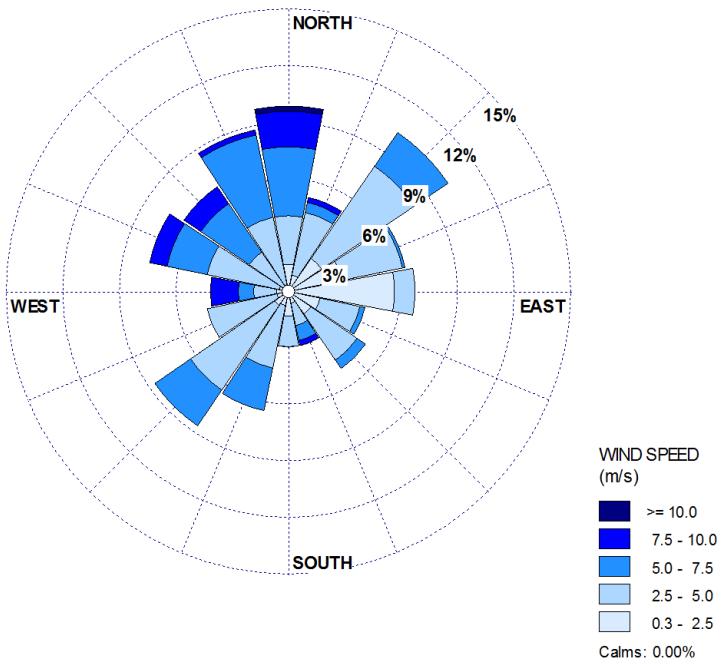


Figure 88 One-hour Wind Roses for the Month of October 2016 from the 50m level

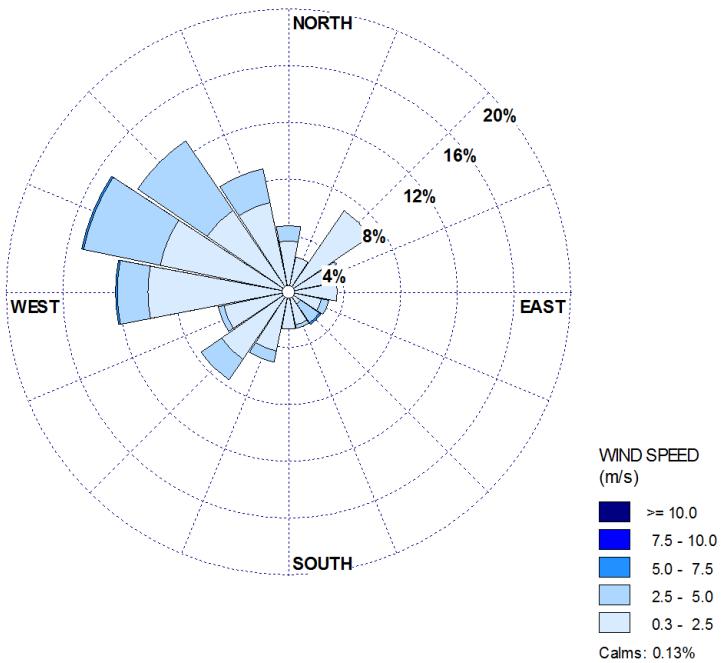


Figure 89 One-hour Wind Roses for the Month of October 2016 from the 10m level

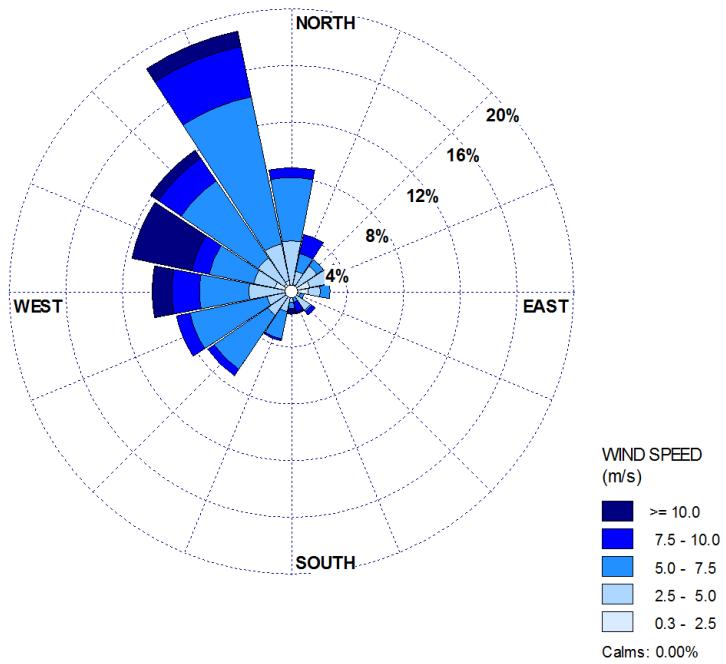


Figure 90 One-hour Wind Roses for the Month of November 2016 from the 85m level

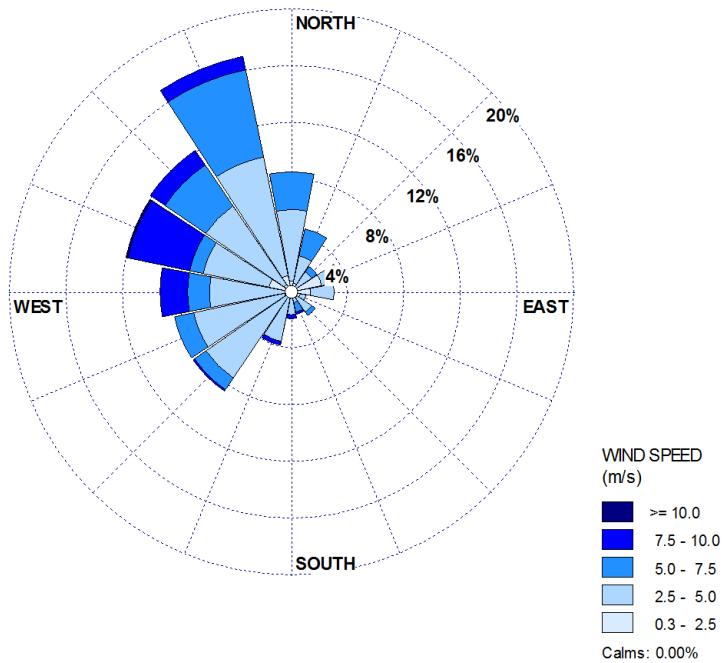


Figure 91 One-hour Wind Roses for the Month of November 2016 from the 50m level

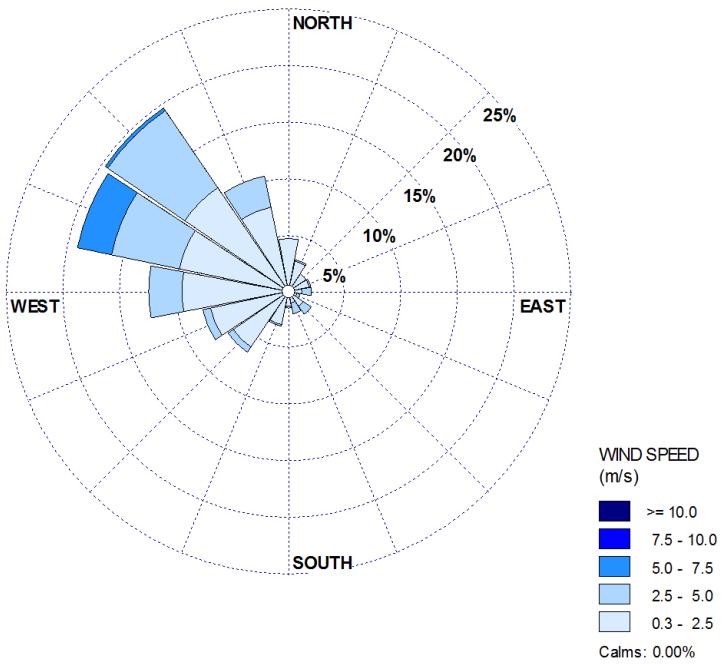


Figure 92 One-hour Wind Roses for the Month of November 2016 from the 10m level

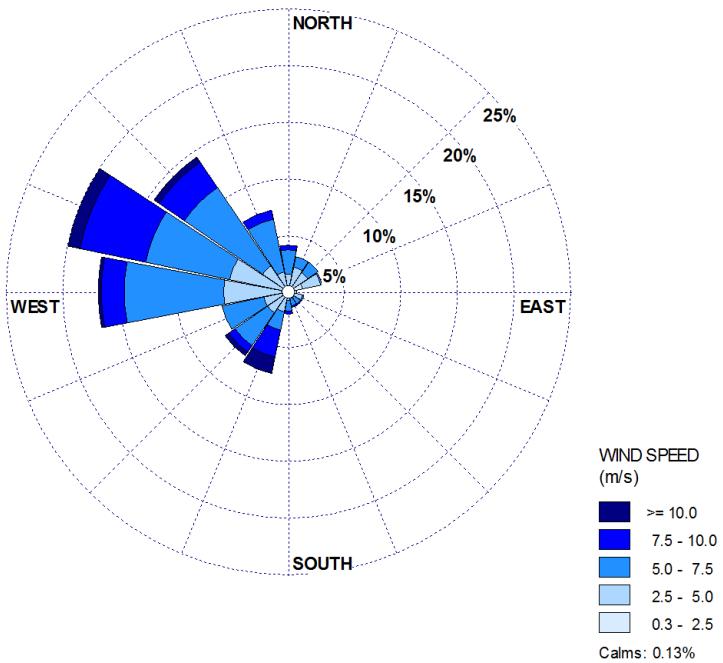


Figure 93 One-hour Wind Roses for the Month of December 2016 from the 85m level

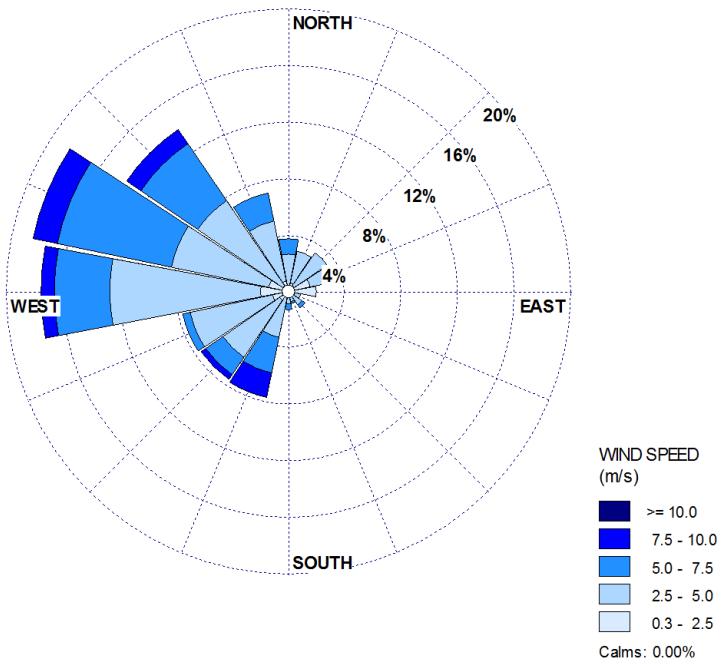


Figure 94 One-hour Wind Roses for the Month of December 2016 from the 50m level

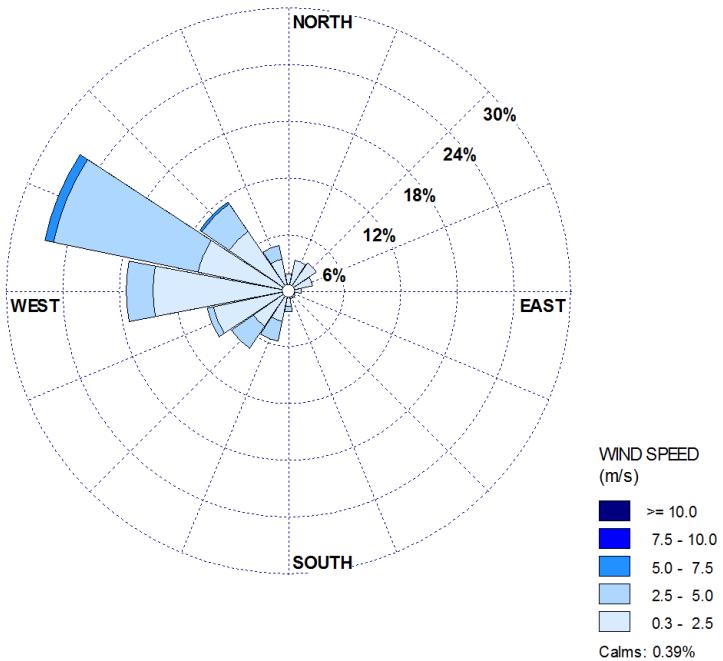


Figure 95 One-hour Wind Roses for the Month of December 2016 from the 10m level

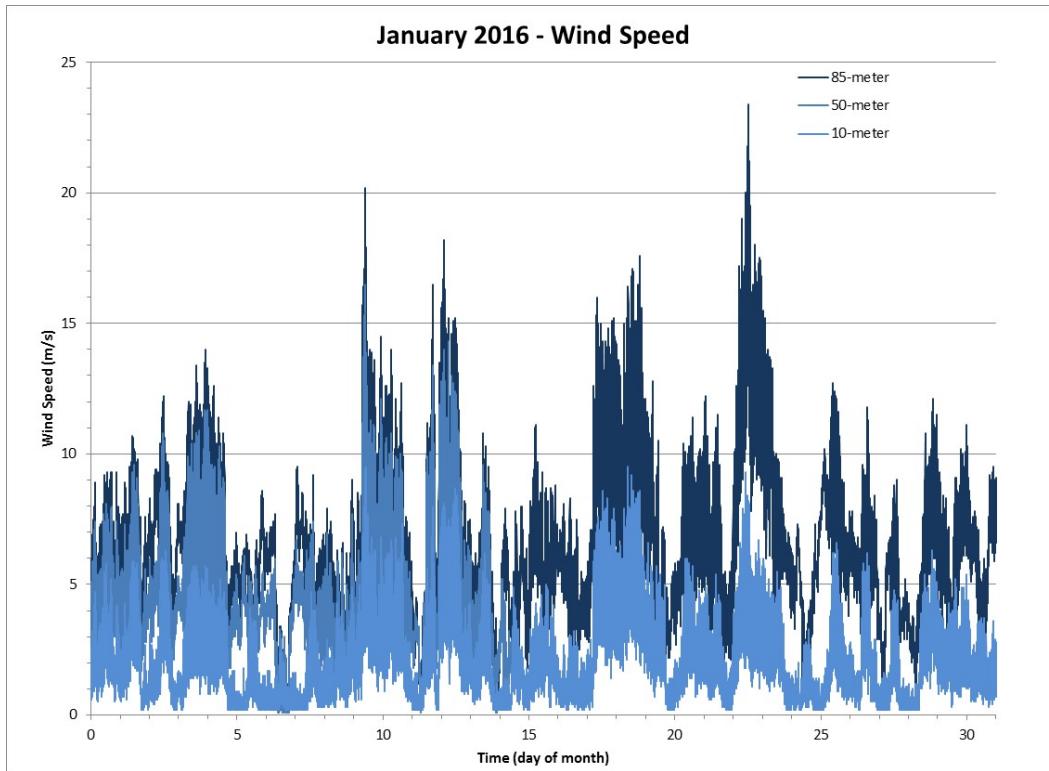


Figure 96 Wind Speed for the Month of January 2016

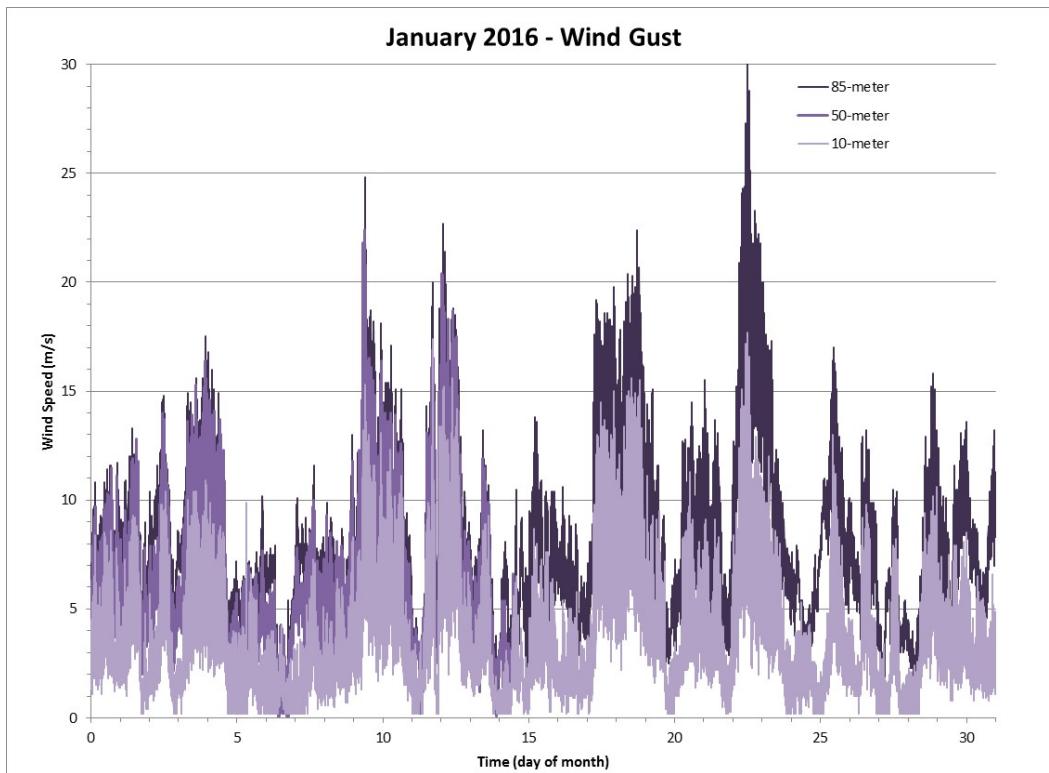


Figure 97 Wind Gust data for the Month of January 2016

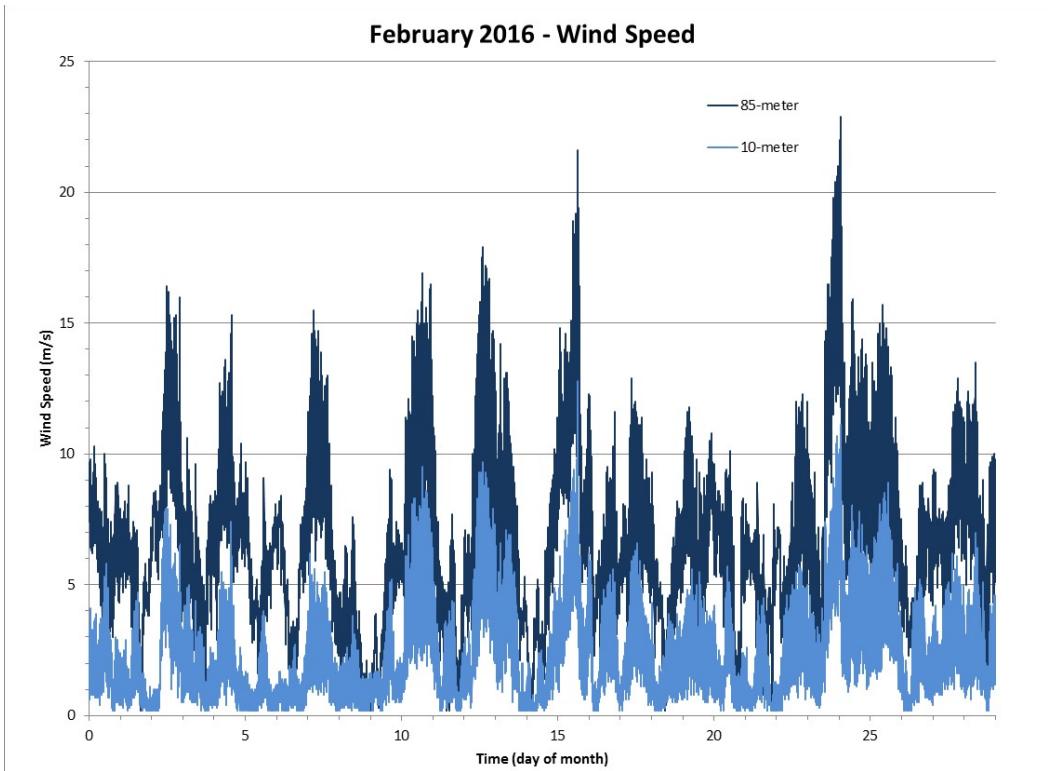


Figure 98 Wind Speed for the Month of February 2016

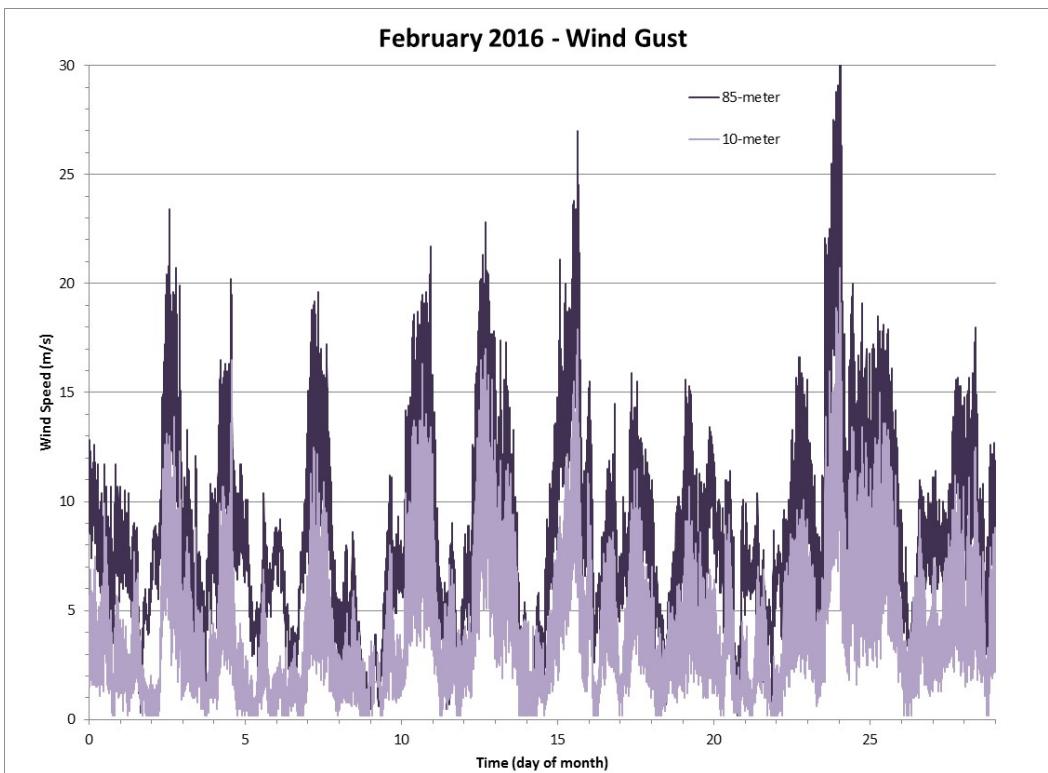


Figure 99 Wind Gust data for the Month of February 2016

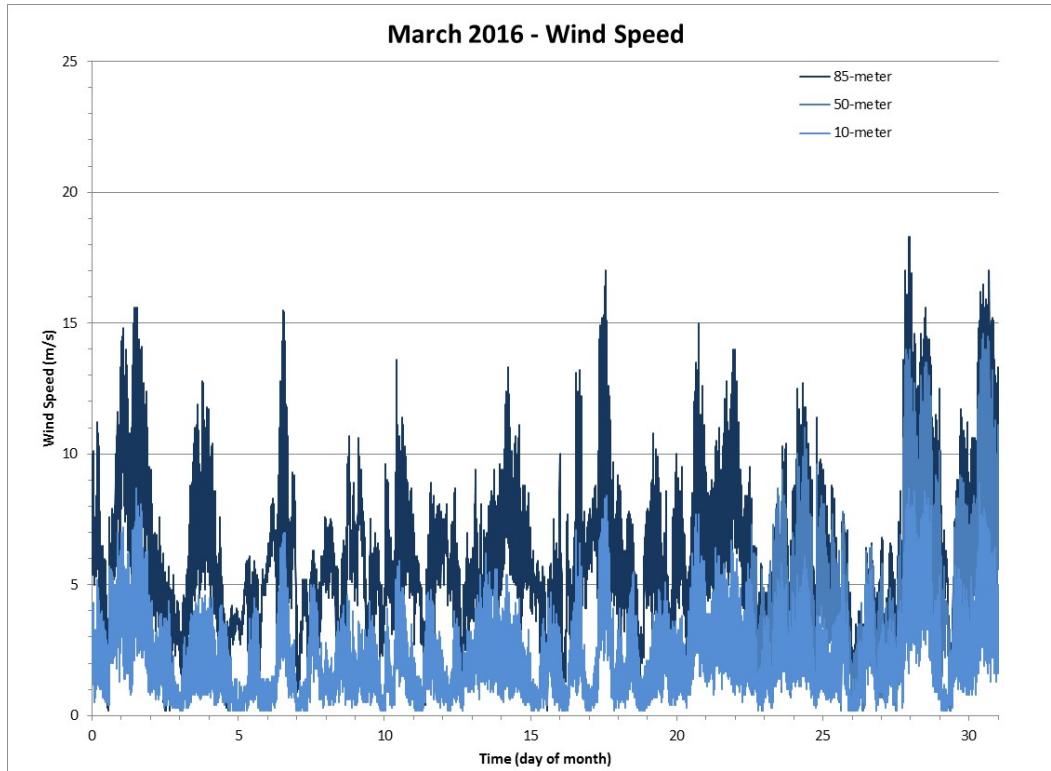


Figure 100 Wind Speed for the Month of March 2016

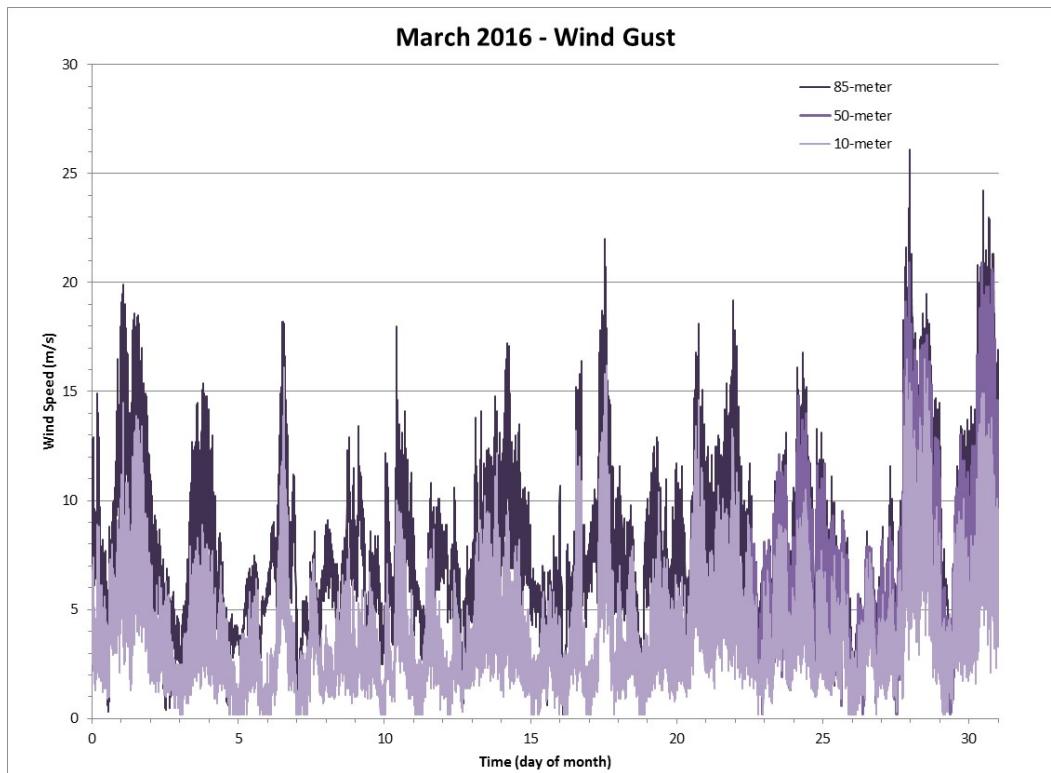


Figure 101 Wind Gust data for the Month of March 2016

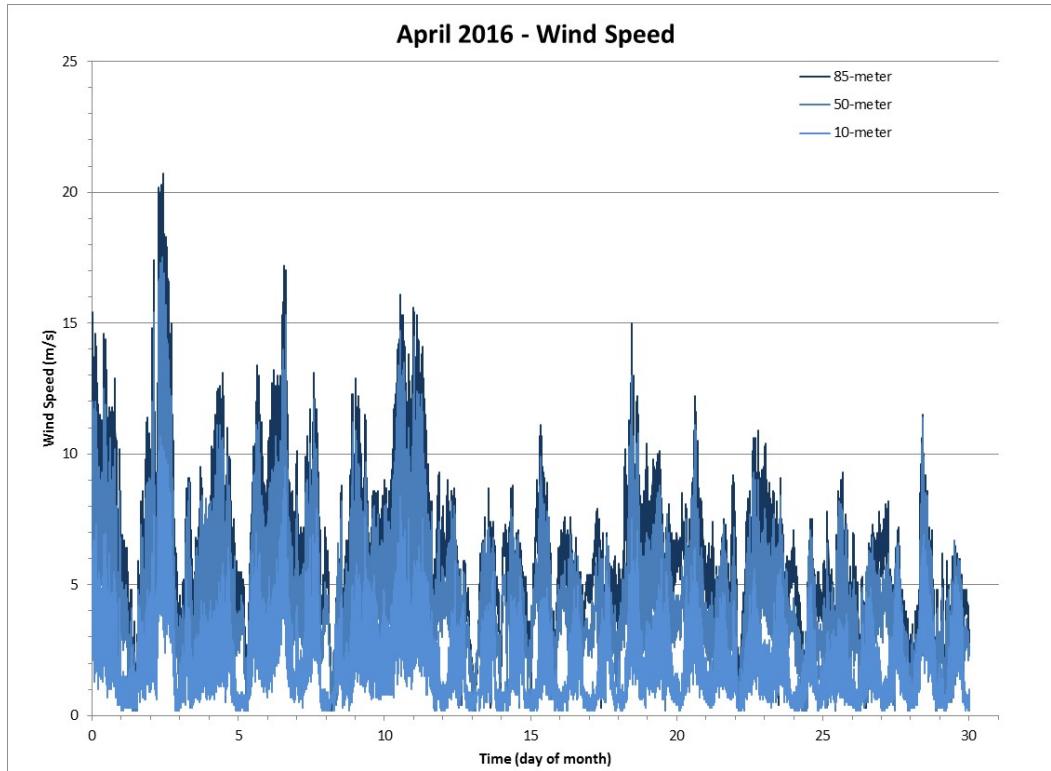


Figure 102 Wind Speed for the Month of April 2016

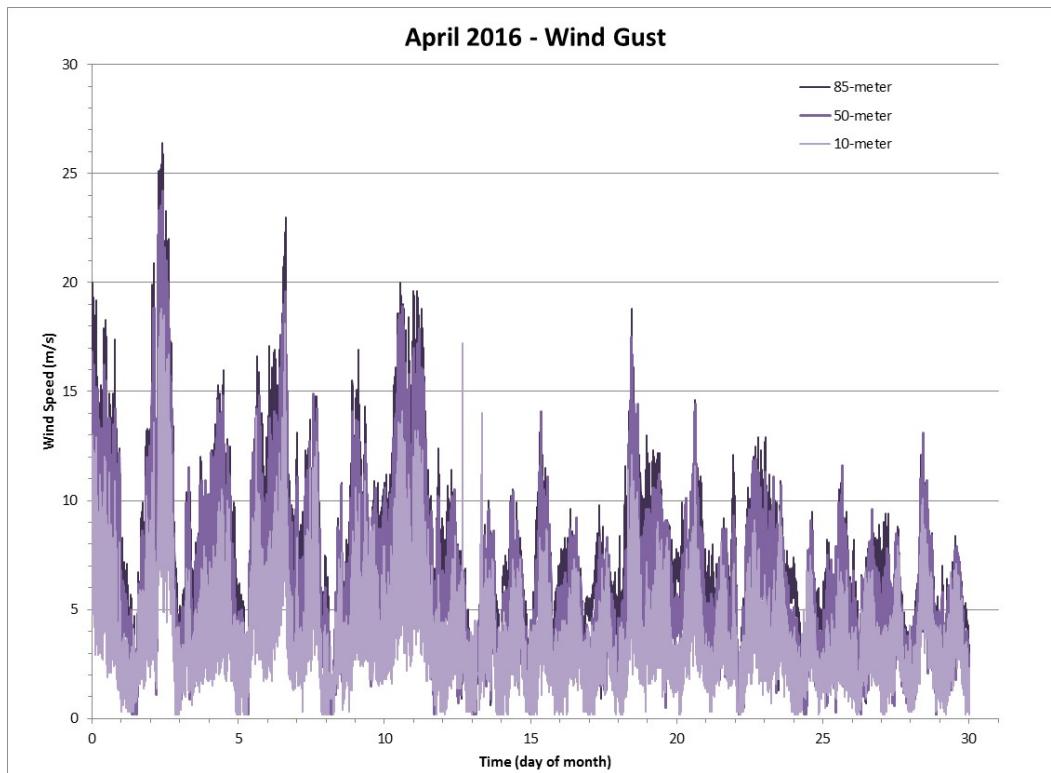


Figure 103 Wind Gust data for the Month of April 2016

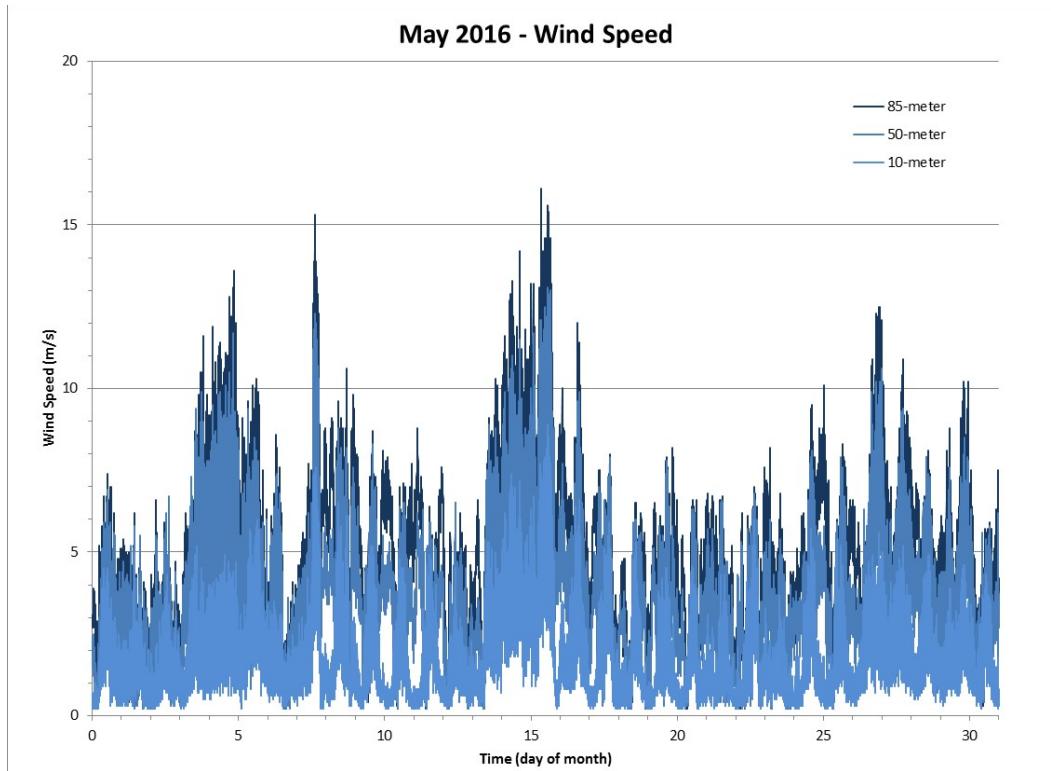


Figure 104 Wind Speed for the Month of May 2016

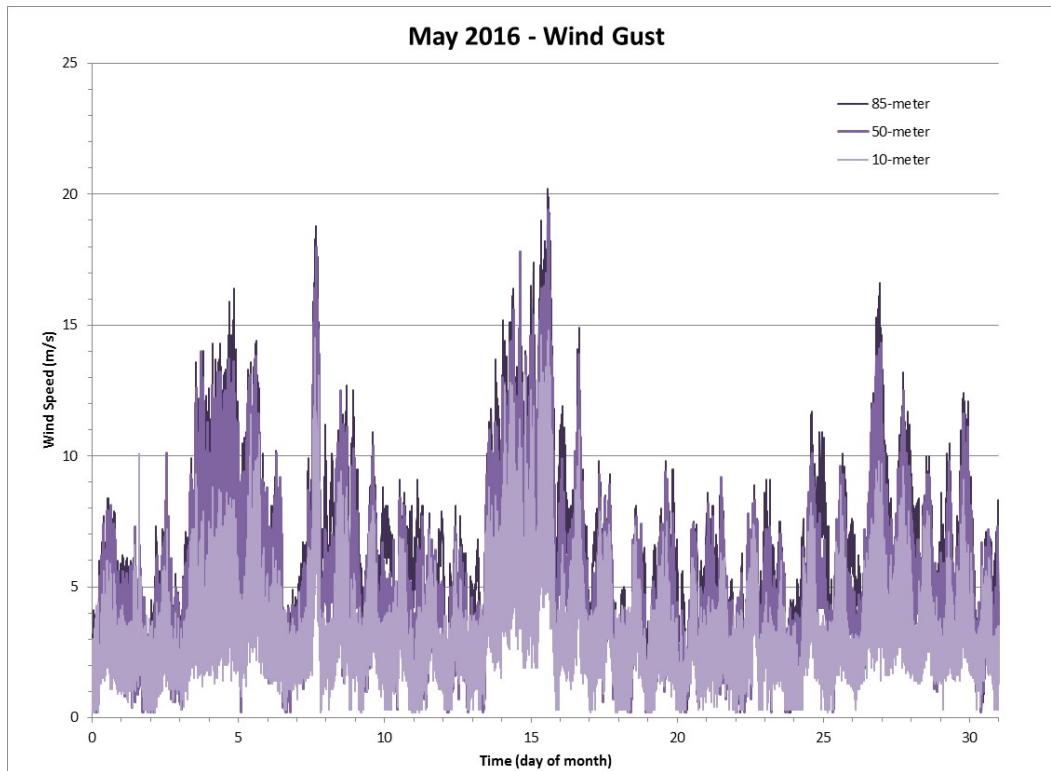


Figure 105 Wind Gust data for the Month of May 2016

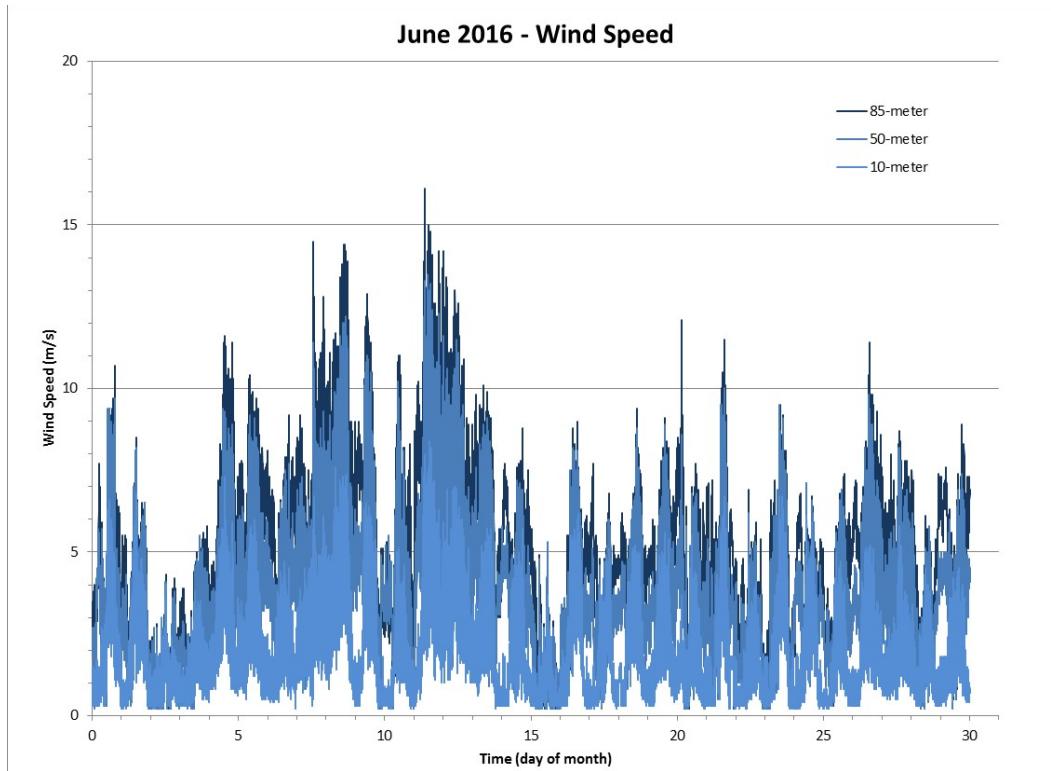


Figure 106 Wind Speed for the Month of June 2016

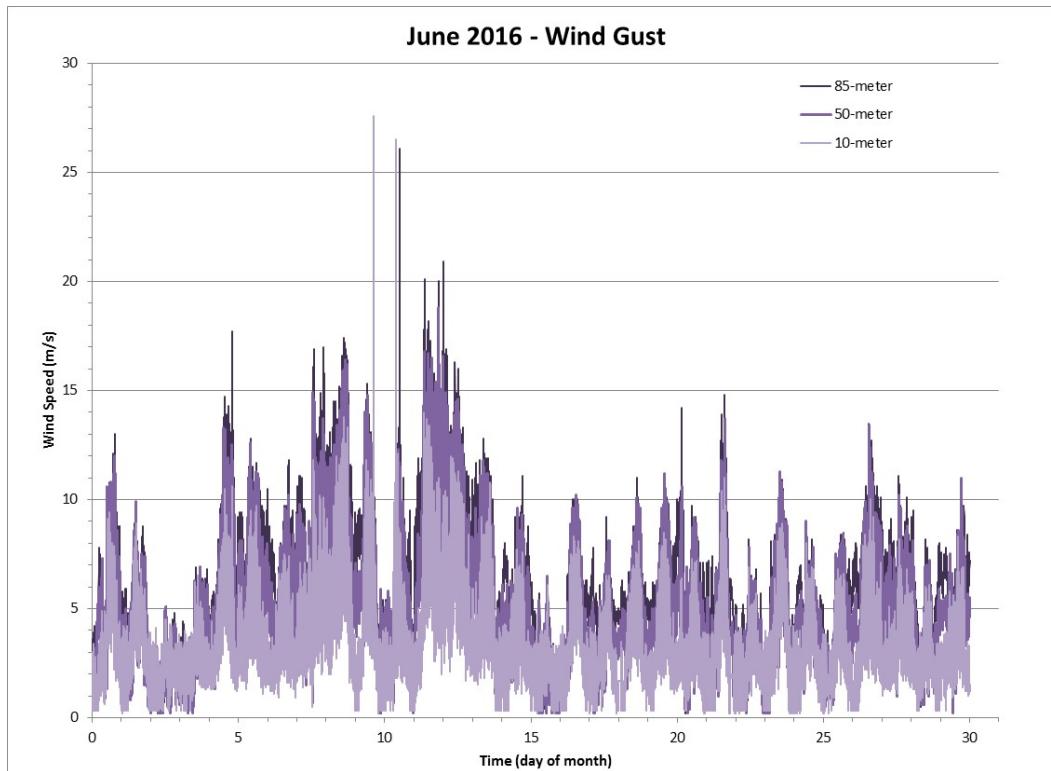


Figure 107 Wind Gust data for the Month of June 2016

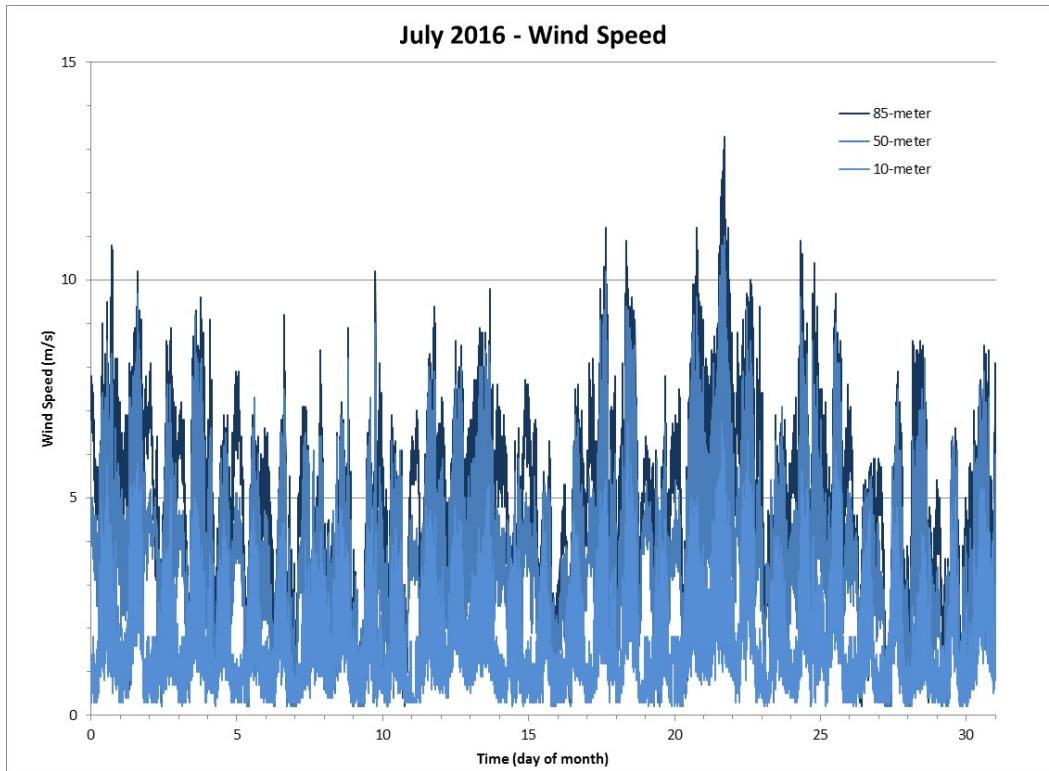


Figure 108 Wind Speed for the Month of July 2016

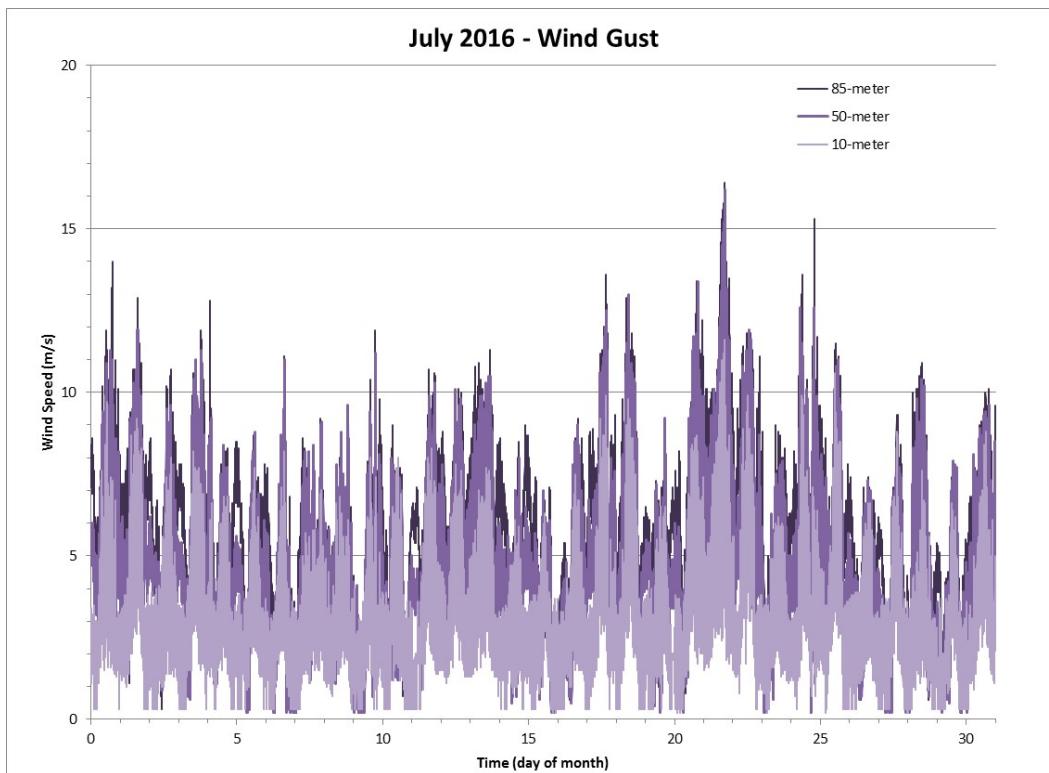


Figure 109 Wind Gust data for the Month of July 2016

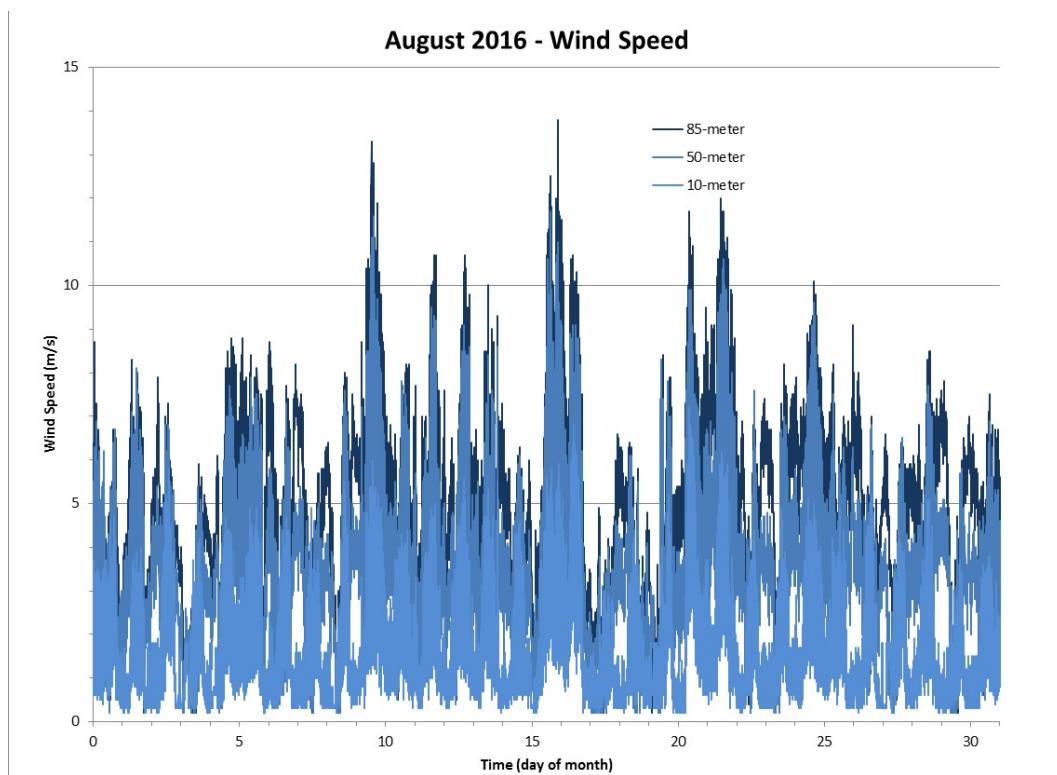


Figure 110 Wind Speed for the Month of August 2016

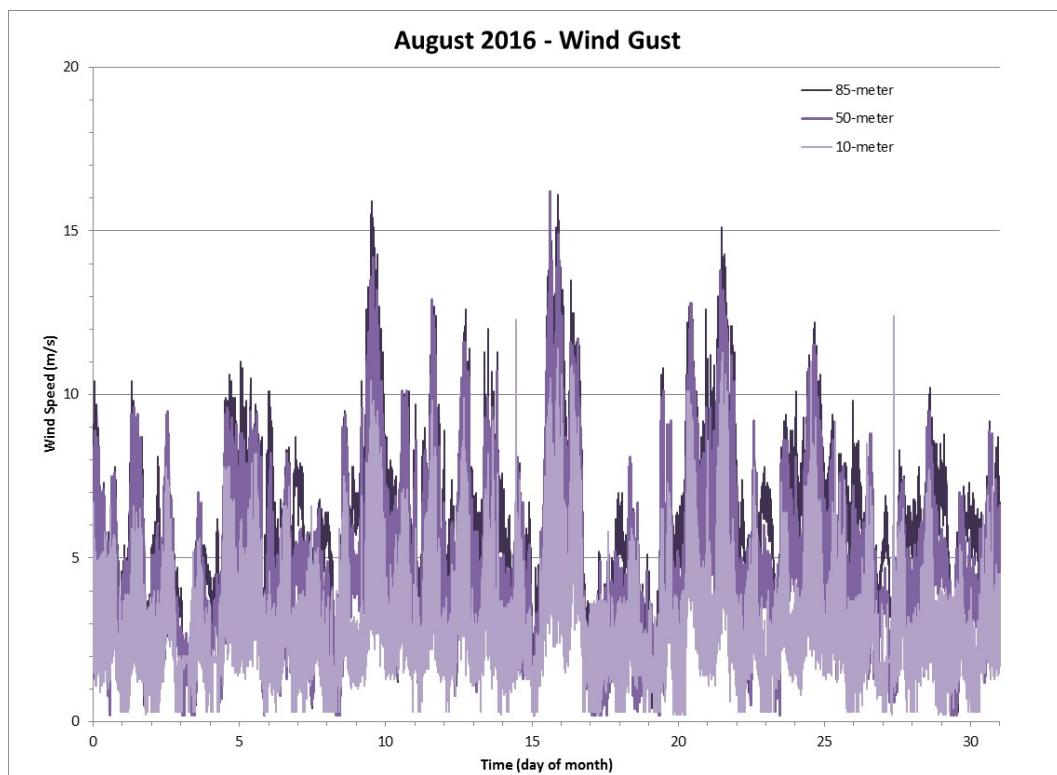


Figure 111 Wind Gust data for the Month of August 2016

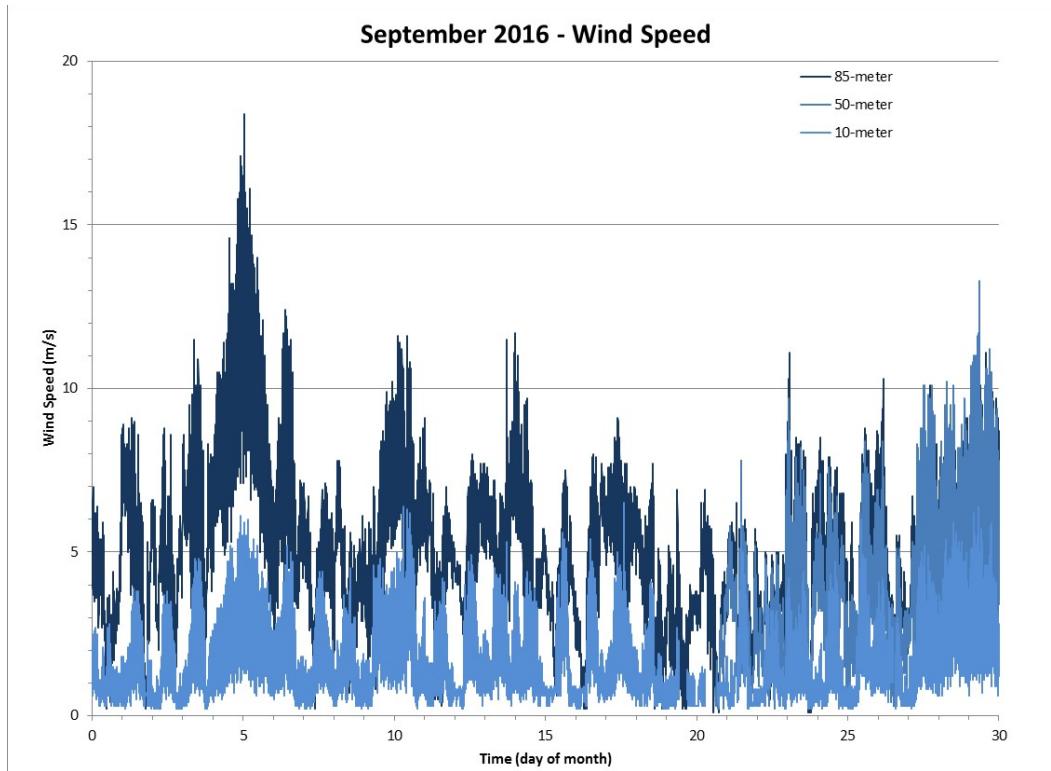


Figure 112 Wind Speed for the Month of September 2016

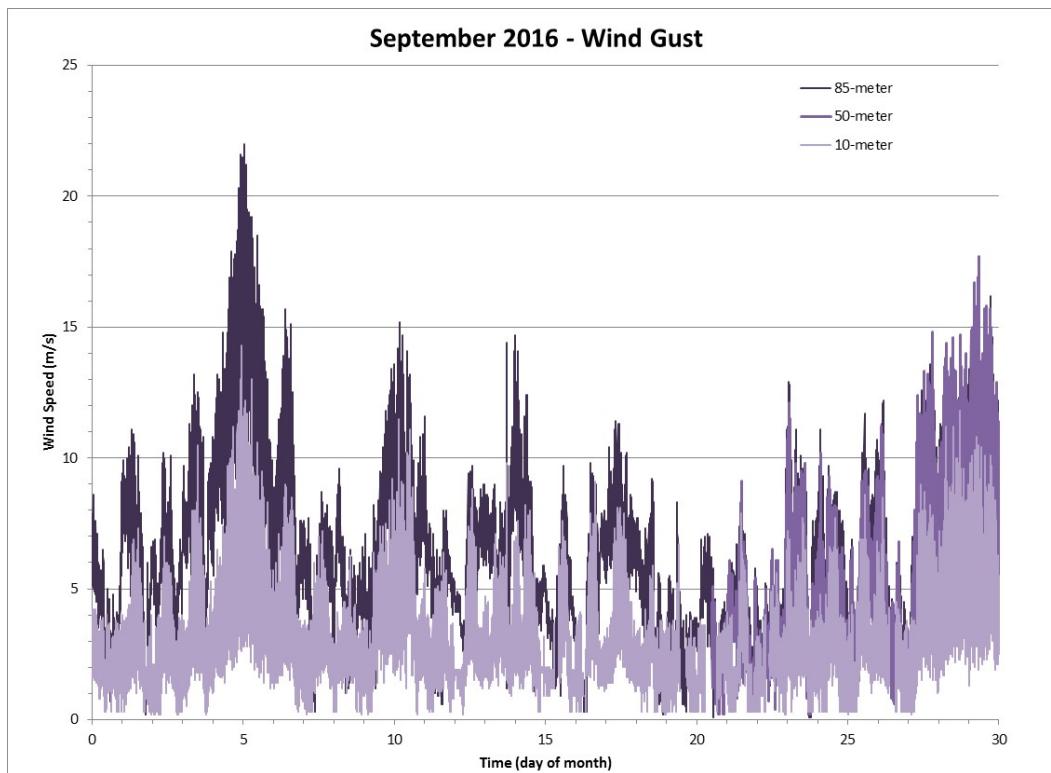


Figure 113 Wind Gust data for the Month of September 2016

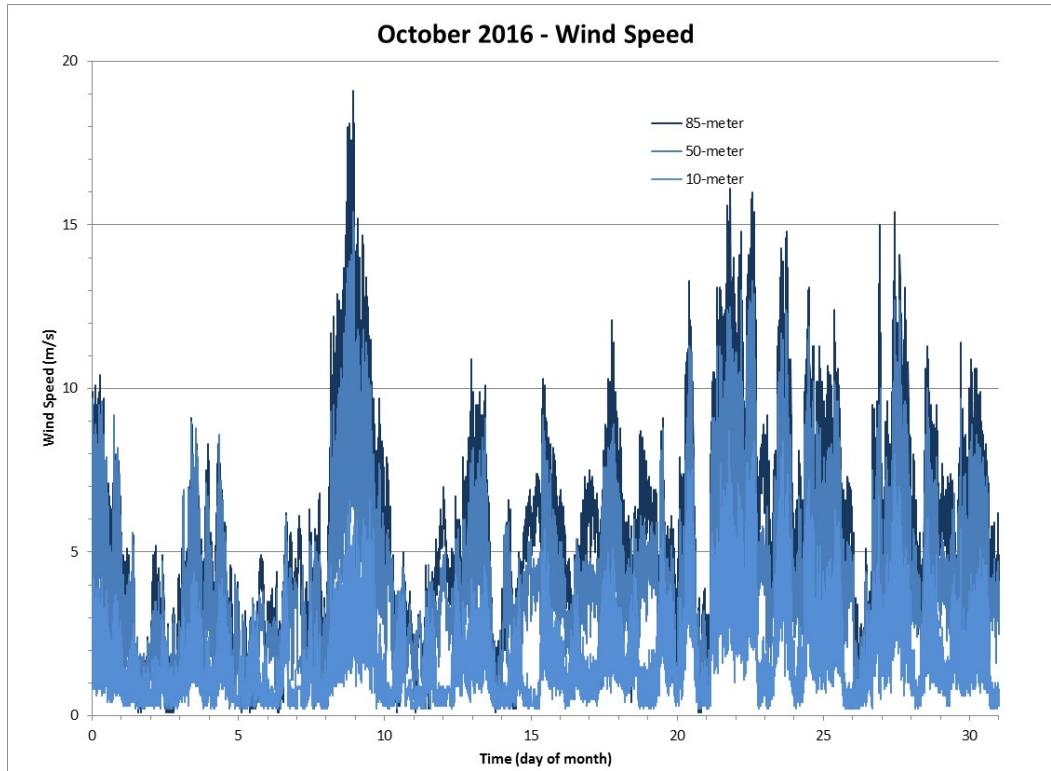


Figure 114 Wind Speed for the Month of October 2016

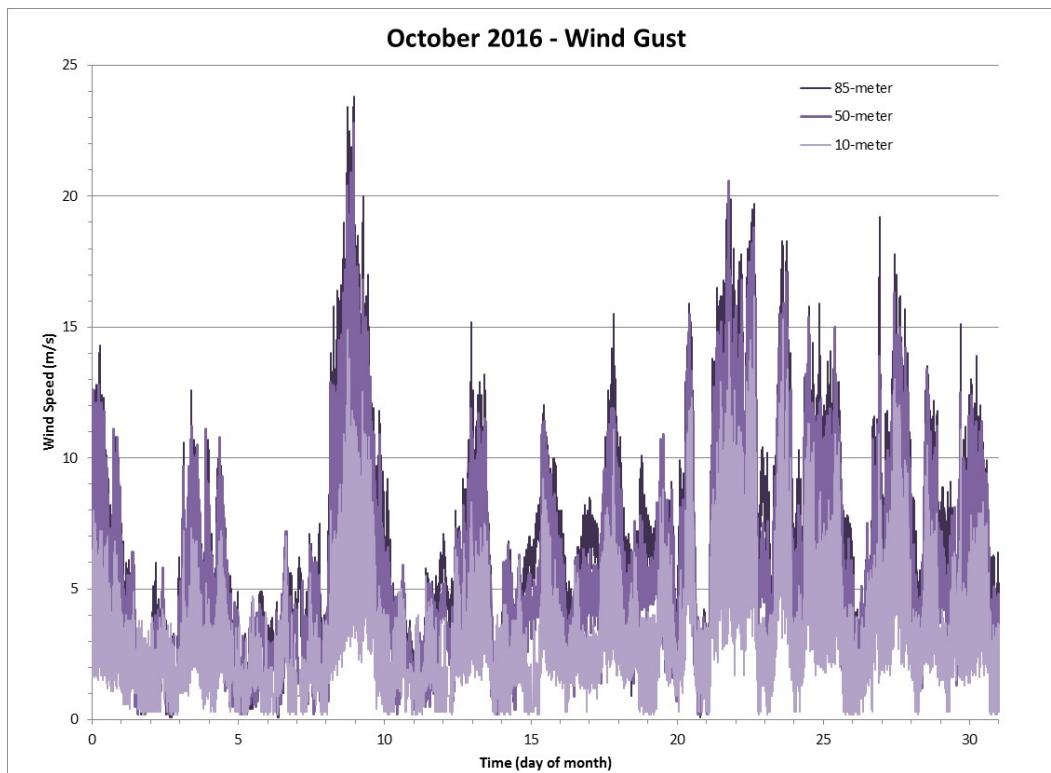


Figure 115 Wind Gust data for the Month of October 2016

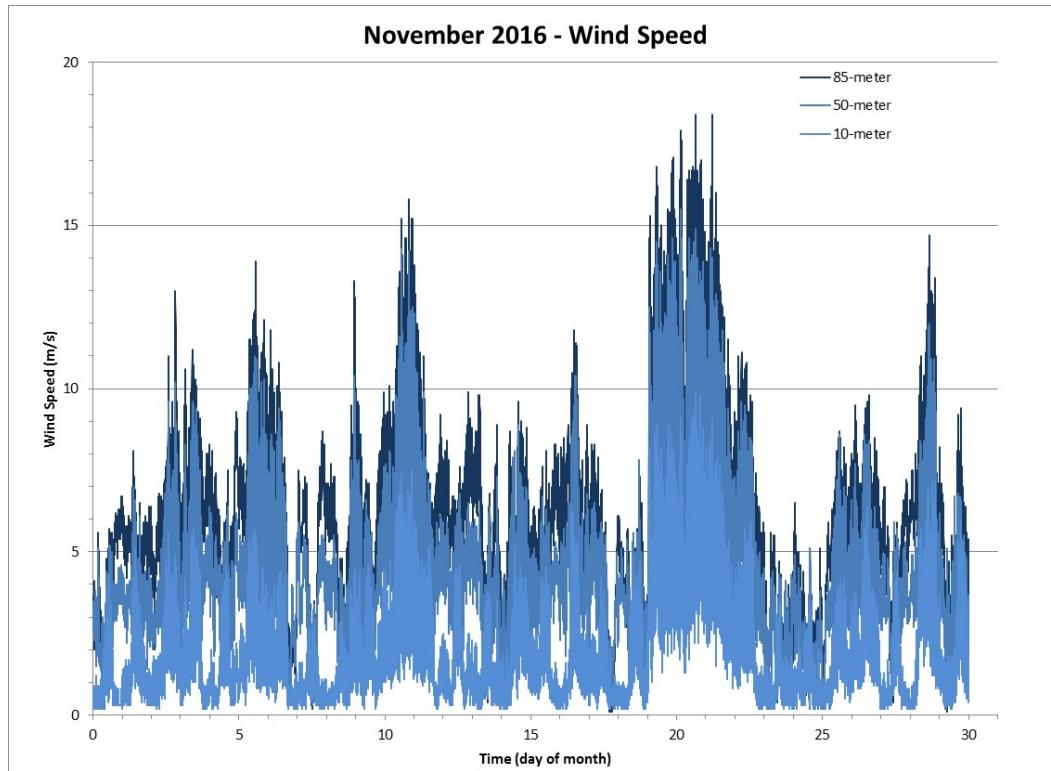


Figure 116 Wind Speed for the Month of November 2016

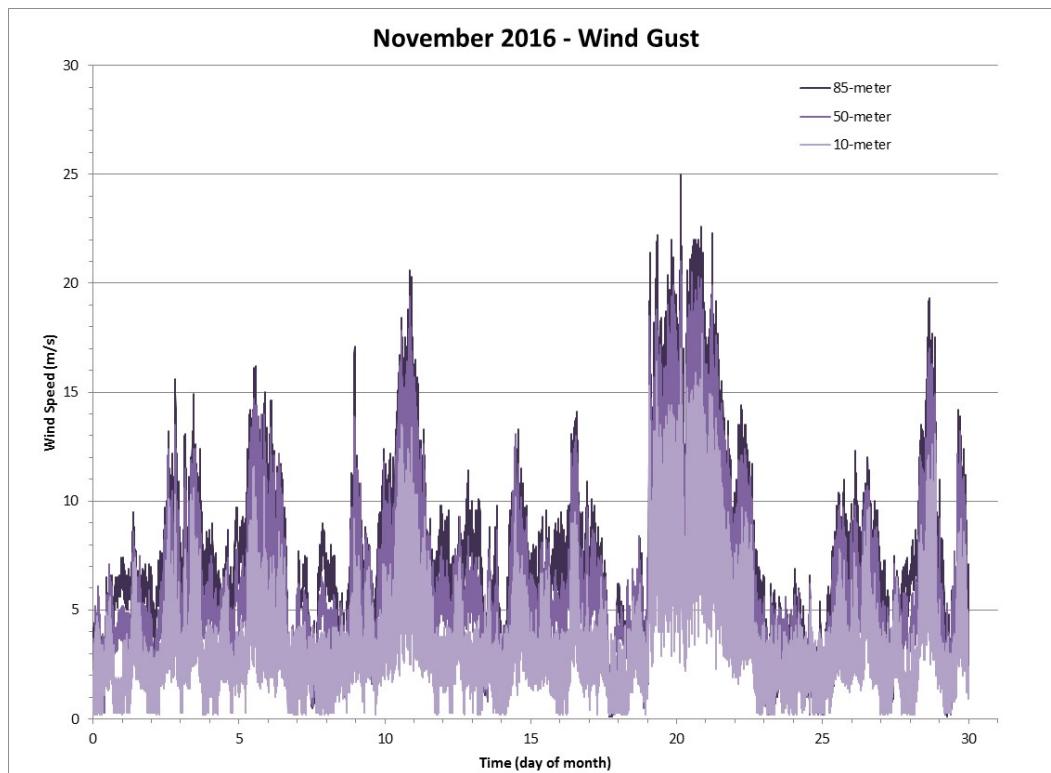


Figure 117 Wind Gust data for the Month of November 2016

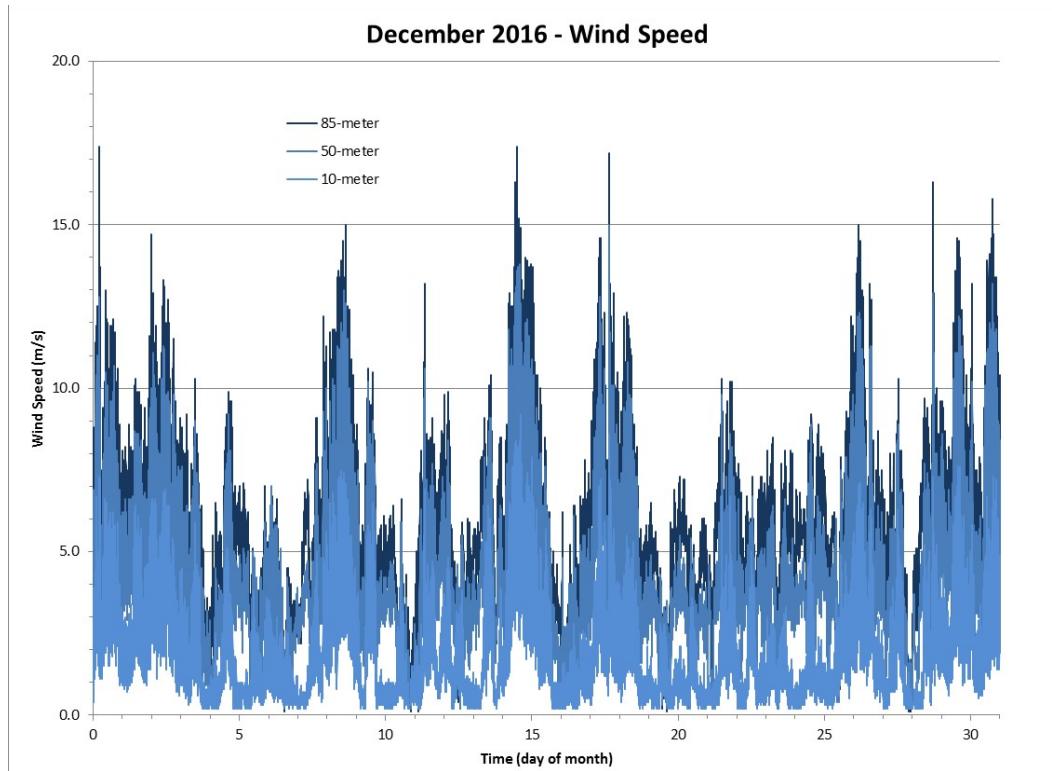


Figure 118 Wind Speed for the Month of December 2016

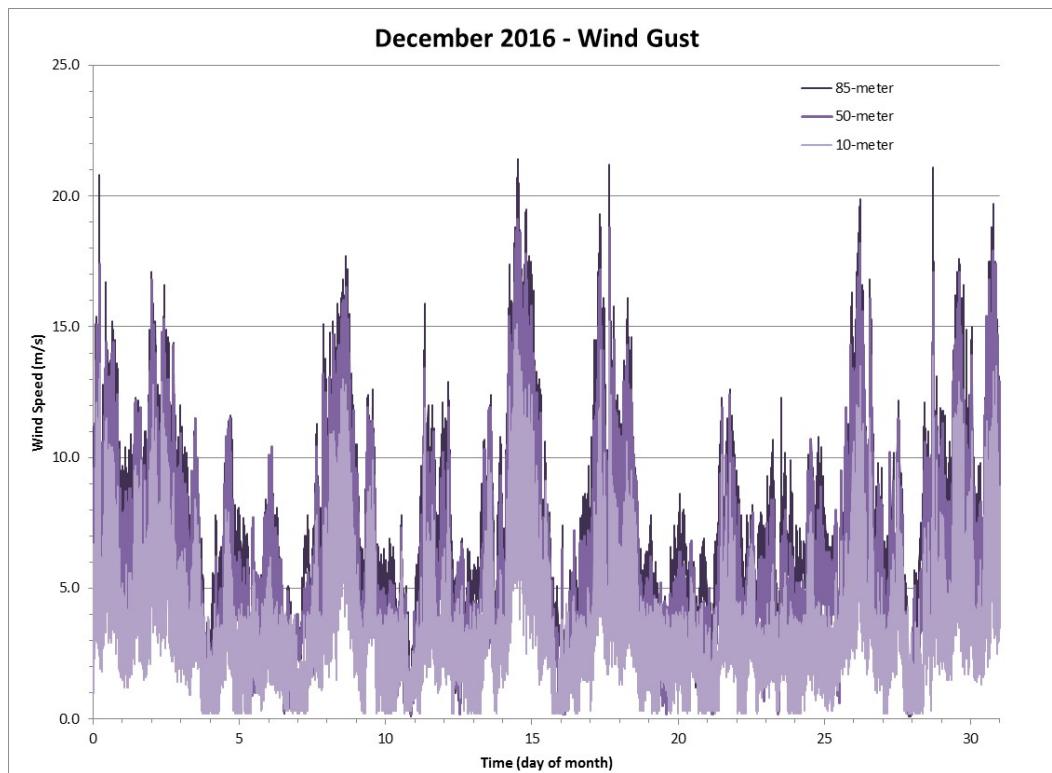


Figure 119 Wind Gust data for the Month of December 2016

2016 Solar Resource Data

Stability class determinations are required for environmental protection, Emergency response and environmental reporting (e.g., CAPP-88 for the USEPA). The best method to determine stability class is the SR-DT (solar radiation-delta temperature) method. To this end Met Services measures global horizontal irradiance. High quality solar resource data is also very important to research in the field of renewable energy. With BNL being home to the Long Island Solar Farm (LISF) and the Northeast Solar Energy Research Center (NSERC), it is important that BNL have a local source of dependable, quality assured data on solar radiation. As such BNL maintains a solar base station that records research grade one-minute data. This section reports solar incidence data including monthly data plots of the one-minute data.

Global Solar Radiation

Global horizontal irradiance (GHI) is the total irradiance falling on a horizontal surface. It is defined by;

$$GHI = DHI + DNI \cdot \cos(\theta_Z)$$

where; DHI = diffuse horizontal irradiance,

 DNI = direct normal irradiance, and

θ_Z = the solar zenith angle (incident angle of the beam)

Global short-wave radiation (near ultraviolet, visible & near-infrared) is measured using a Kipp & Zonen CMP-22 pyranometer attached to a powered ventilator and mounted on a SOLYS-2 sun tracker. This unit is sent off-site for calibration in the NREL BORCAL program. Currently, when the unit is out for calibration it is replaced with a calibrated CMP-21 pyranometer. The CMP-21 is a high precision research grade pyranometer that includes an integrated housing temperature sensor. The CMP-22 is also a high precision research grade pyranometer with a higher optical quality and higher refractive index quartz dome housing the sensor. Figures 126 through 137 present the monthly plots of global solar radiation.

Figure 120 presents the peak global solar irradiance at BNL for 2016. Figure 121 presents the average daily global solar irradiance at BNL for 2016. Figure 122 shows the monthly average daily irradiance for global and in-plane (angled to match the LISF panels). Table 7 gives the 2016 and historical monthly daily averages for global solar irradiance.

Table 7 Average Daily Solar Irradiance (Global) at BNL by Month (W/m²)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1994	72.2	116.7	147.7	207.9	246.9	265.2	259.8	193.4	187.5	152.3	92.6	72.5	167.9
1995	74.9	108.1	182.7	231.9	281.6	168.3	97.4	301.1	290.0	151.1	85.5	77.4	170.8
1996	63.2	113.9	171.6	193.7	242.0	239.0	222.8	227.1	158.6	145.2	92.9	52.5	160.2
1997	80.1	119.4	152.4	226.6	261.3	283.7	288.6	225.2	180.4	145.4	78.4	70.8	176.0
1998	72.4	113.4	146.5	215.0	243.3	283.5	268.4	255.5	204.3	139.5	98.3	64.7	175.4
1999	73.5	114.4	195.3	223.2	249.6	285.3	270.1	223.9	219.4	156.0	97.1	77.6	182.1
2000	82.7	122.4	182.8	171.7	278.3	267.5	265.5	212.8	208.4	194.6	120.7	81.9	182.4
2001	81.7	125.1	148.3	220.6	289.4	281.5	284.2	227.5	202.6	159.3	105.9	74.7	183.4
2002	78.0	162.4	161.2	230.5	264.4	289.4	291.7	271.6	191.7	122.8	78.8	70.3	184.4
2003	83.9	74.3	174.1	191.8	190.4	262.6	249.8	294.6	175.3	118.8	80.4	58.8	162.9
2004	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2005	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2006	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2007	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2008	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2009	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2010	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2011	86.2	121.1	177.5	172.6	223.6	254.2	276.7	223.7	130.0	130.3	97.5	75.2	164.1
2012	91.5	126.5	163.7	254.3	199.2	268.3	249.0	231.8	179.6	110.0	92.8	59.8	168.9
2013	82.6	109.8	163.0	243.9	236.7	256.7	239.0	210.4	189.8	128.6	96.1	60.9	168.1
2014	80	121	159	223	237	277	263	239	185	116	86	56	170
2015	80	119	161	211	262	233	252	250	200	137	88	57	171
2016	93	106	175	221	209	286	258	234	165	127	99	69	170
Average	80	117	166	215	245	263	252	239	192	140	93	67	172
Max	93	162	195	254	289	289	292	301	290	195	121	82	184
Min	63	74	147	172	190	168	97	193	130	110	78	53	160

nan indicates missing data, Values in fields filled in yellow are the monthly averages inserted because of partially missing data, the average then changes with addition of this value.

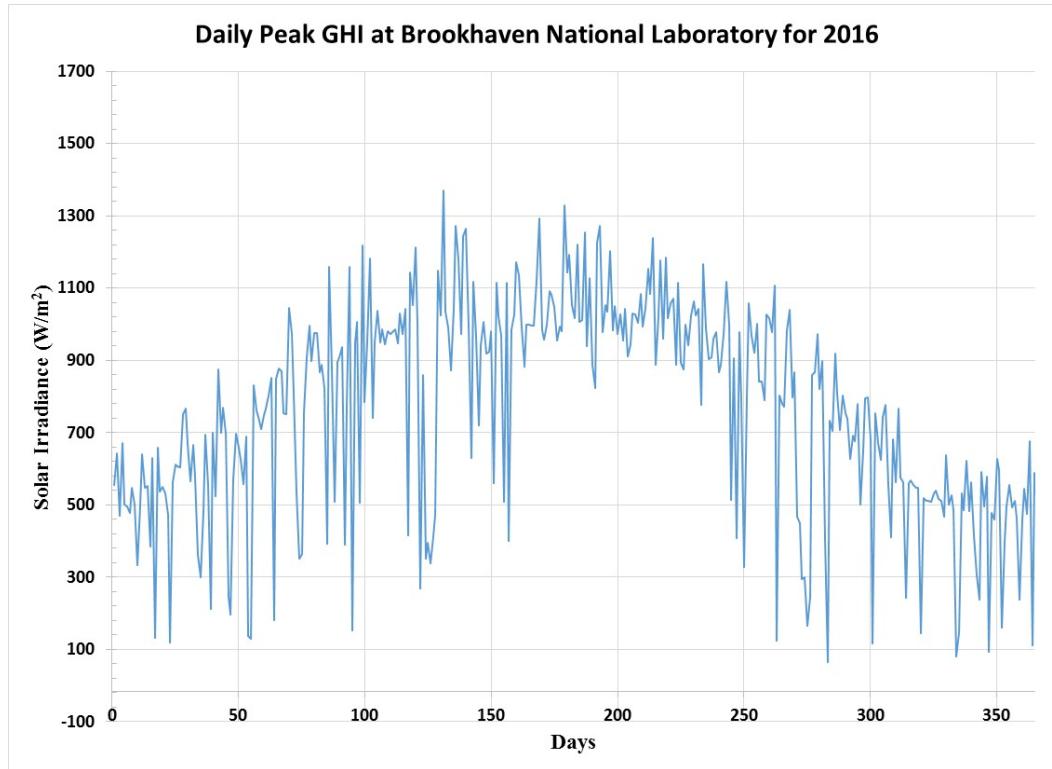


Figure 120 Daily Peak Solar Irradiance at Brookhaven National Laboratory for 2016

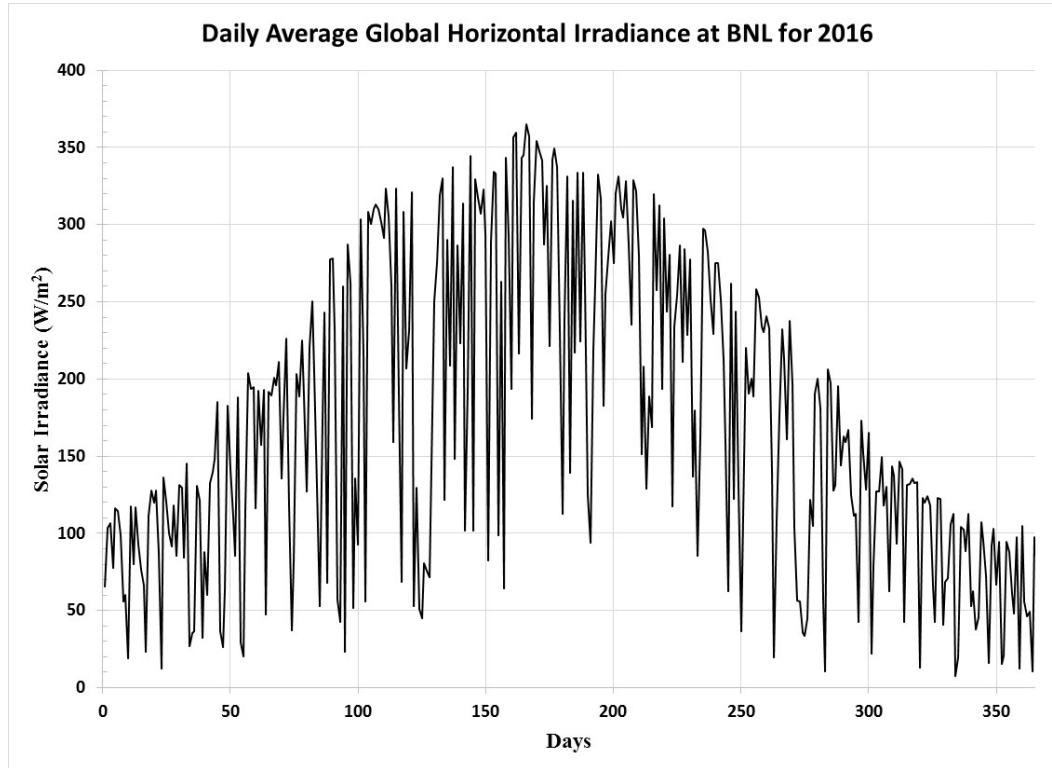


Figure 121 Average Daily Solar Irradiance at Brookhaven National Laboratory for 2016

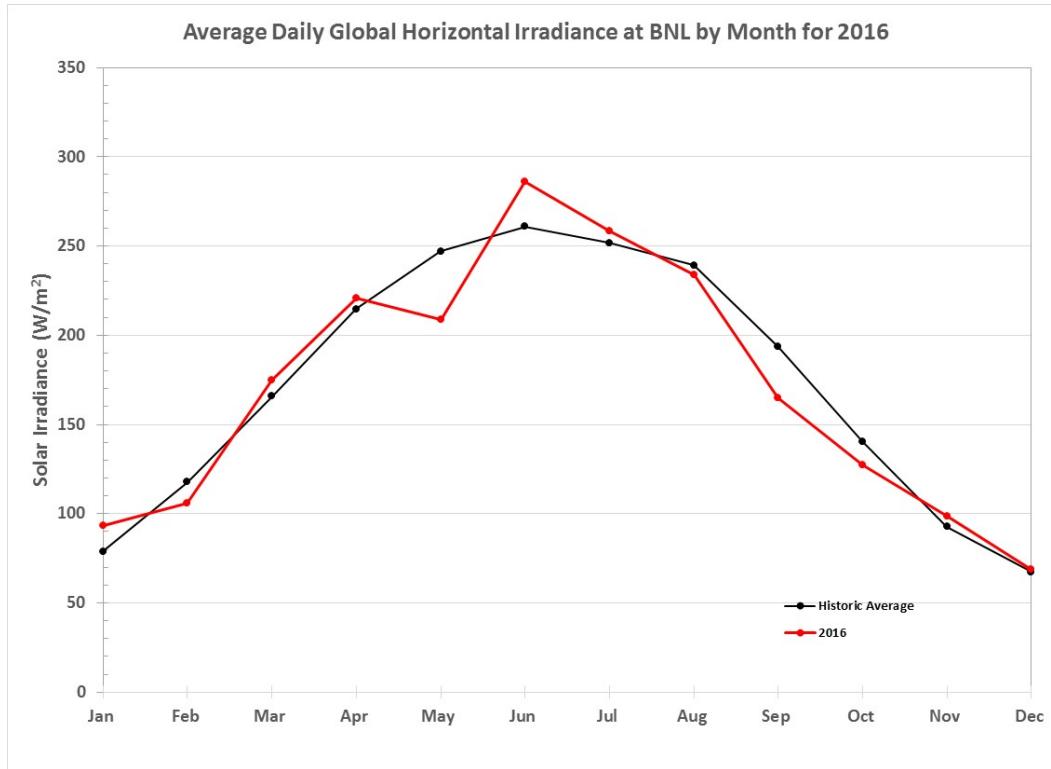


Figure 122 Global Horizontal Irradiance – 2016 Monthly Daily-Average

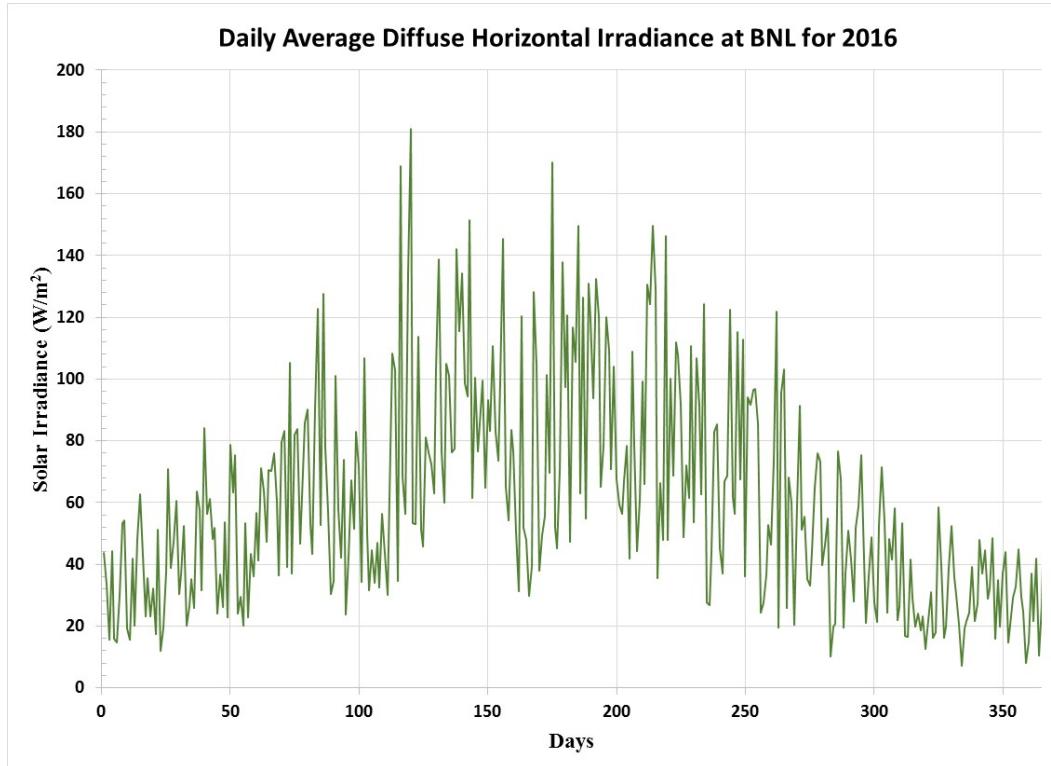


Figure 123 Average Daily Diffuse Solar Irradiance at Brookhaven National Laboratory for 2016

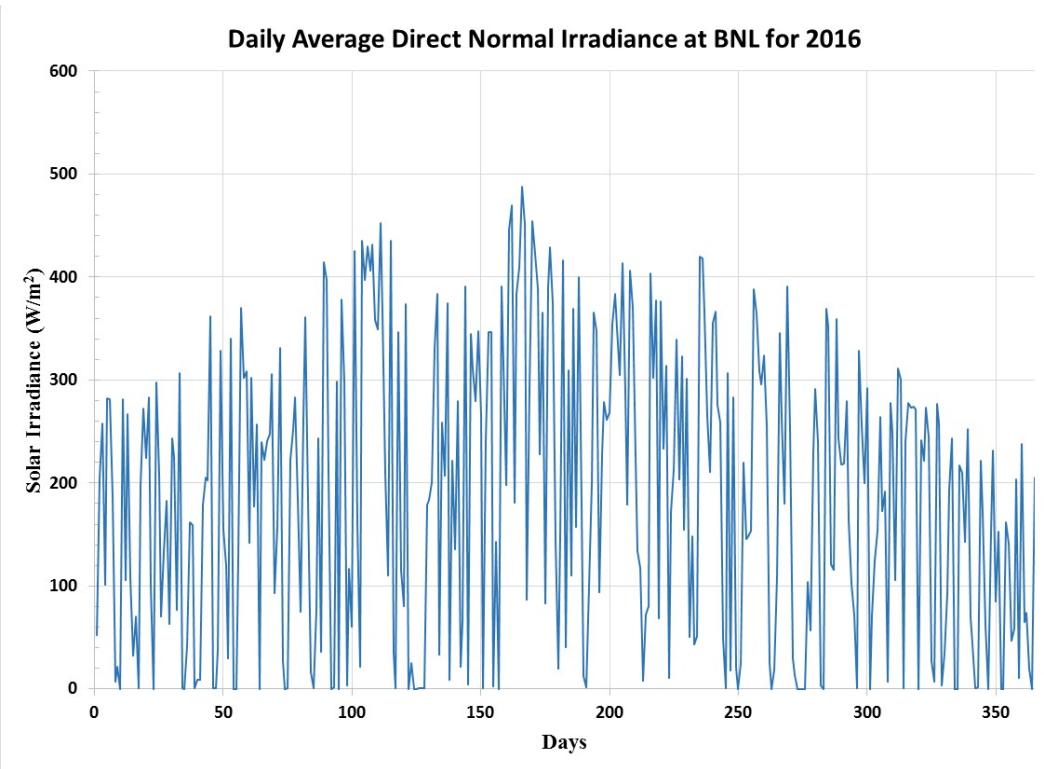


Figure 124 Average Daily Direct Normal Solar Irradiance at Brookhaven National Laboratory for 2016

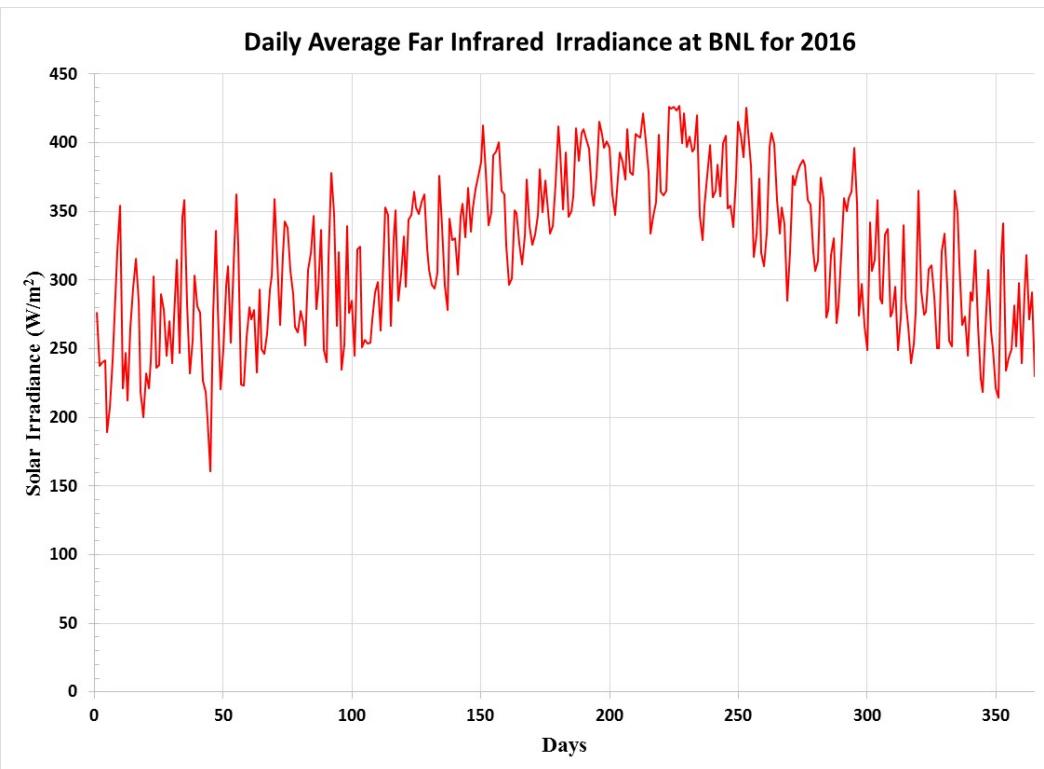


Figure 125 Average Daily Long-wave Far Infrared Irradiance at Brookhaven National Laboratory for 2016

Diffuse Solar Radiation

Diffuse solar irradiance is the radiation that is scattered (i.e., by clouds and dust particles) as it passes through the atmosphere. Diffuse short-wave radiation (ultraviolet, visible & near-infrared) is measured using a shaded Kipp & Zonen CMP-22 pyranometer with a powered ventilator mounted on a SOLYS-2 sun tracker. This unit is sent off-site for calibration in the NREL BORCAL program. Currently, when the unit is out for calibration it is replaced with a calibrated CMP-21 pyranometer. Figure 123 gives the average daily diffuse irradiance for the year. Figures 138 through 149 present the monthly plots of diffuse solar radiation.

Direct Solar Radiation

Direct normal irradiance (DNI) is the solar radiation that travels in a straight path to a detector that is perpendicular to the light path. The direct short-wave radiation is measured with a Kipp & Zonen CHP-1 pyrheliometer attached to a SOLYS-2 sun tracker. The CHP-1 is a thermopile that absorbs 97-98% of the total incident radiation. The reported maximum uncertainty is 2% for hourly measurements and 1% for daily totals. Figure 124 gives the average daily direct normal irradiance for the year. Figures 150 through 161 present the monthly plots of direct solar radiation.

Long-wave Far Infrared Radiation

Downward long-wave far infrared radiation is measured using a shaded Kipp & Zonen CGR-4 pyrgeometer with a powered ventilator mounted on the SOLYS-2 sun tracker. The CGR-4 is a research grade thermopile. This unit is sent off-site for calibration in the NREL BORCAL program. A duplicate unit is stocked which is sent to NREL for calibration and replaces the in service unit when returned. The CGR-4 has a built in temperature sensor and temperature correction is applied. The reported maximum daily uncertainty is 3%. Figure 125 gives the average daily long-wave infrared irradiance. Figures 162 through 173 present the monthly plots of long-wave infrared irradiance.

LISF and NSERC Reference Pyranometers

The Long Island Solar Farm (LISF) and NorthEast Solar Research Center (NSERC) both have a network of pyranometers and meteorological sensors to provide data for solar research. Each of the 25 LISF powerblocks and the three areas of NSERC has a pair of Kipp & Zonen pyranometers that measure global and tilted global solar radiation. As a reference for the LISF sensor array, two Kipp and Zonen model SP-lite2 pyranometers are maintained at the base station on building 490D, one in-plane (tilted global radiation) at the 27° angle of inclination used for the panels at the LISF and one horizontal (global radiation). A corresponding set of SP-lite2 pyranometers are maintained for the NSERC with the in-plane at an angle of 23°. The

horizontal (global) solar radiation plots, as measured via SP-lite2 pyranometers, are presented in Figures 174 through 185. The in-plane or tilted global radiation for both LISF and NSERC is presented in Figures 186 through 209.

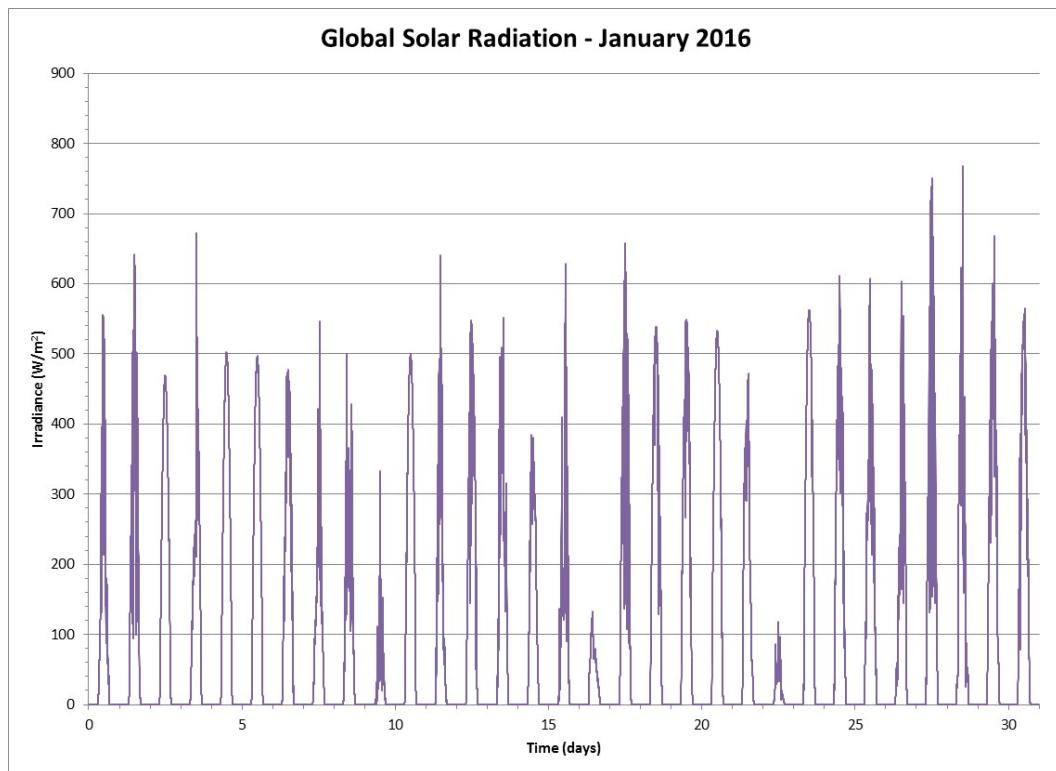


Figure 125 Global Solar Radiation for the Month of January 2016

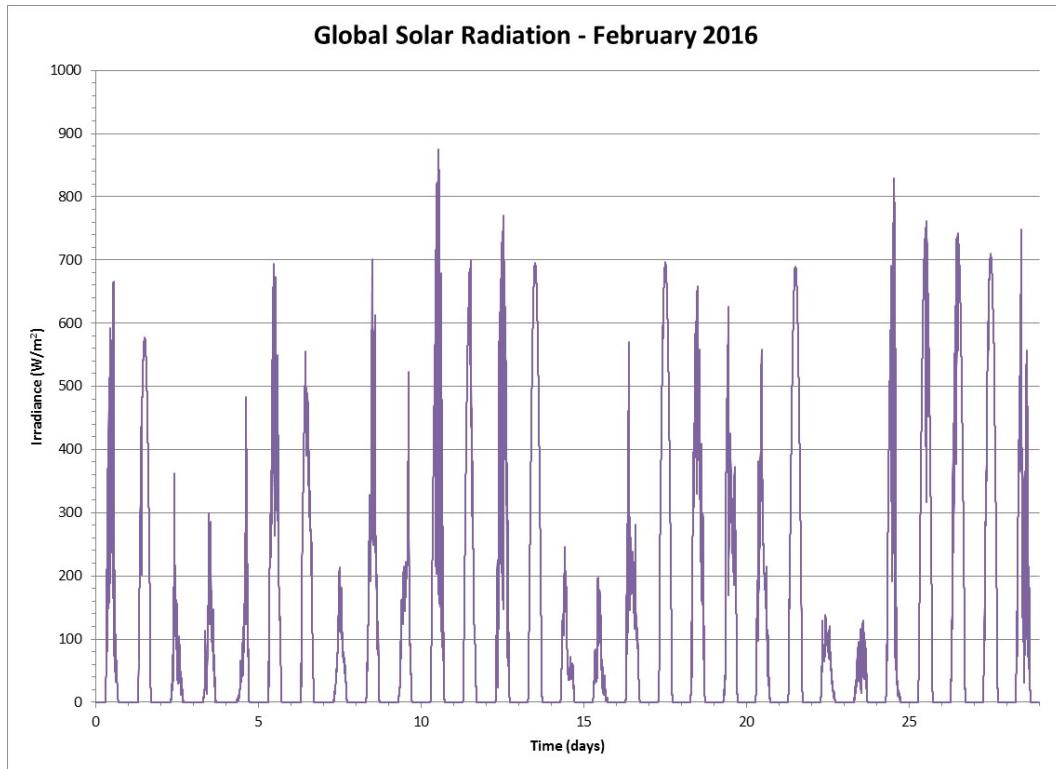


Figure 126 Global Solar Radiation for the Month of February 2016

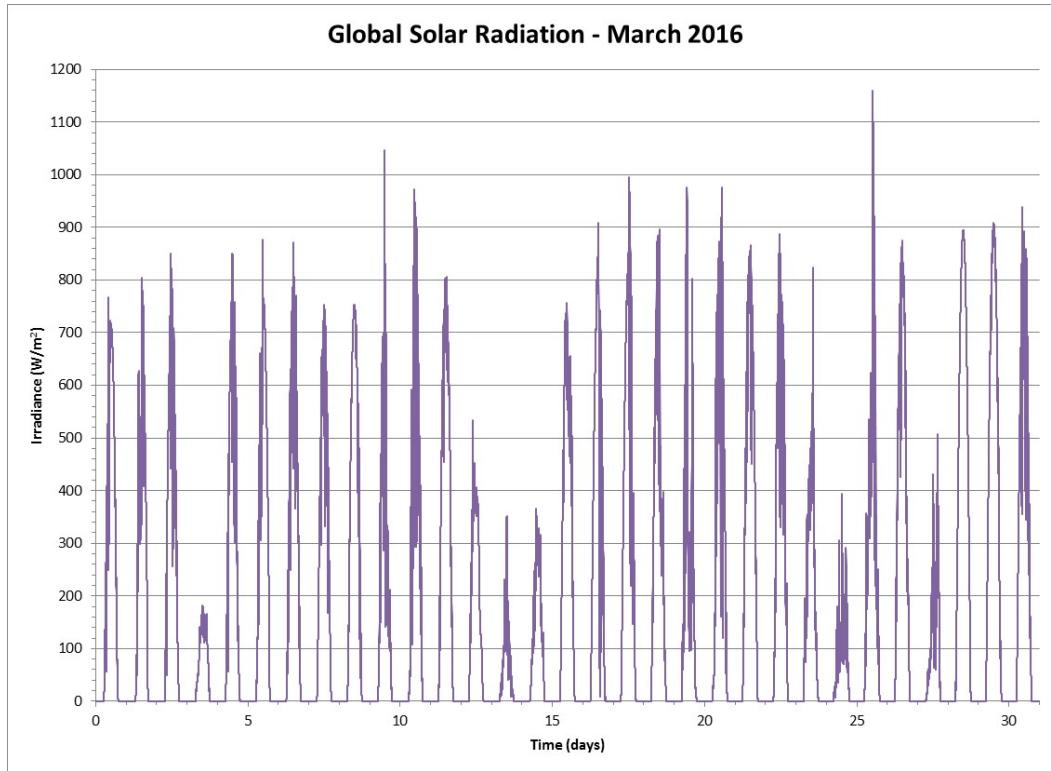


Figure 127 Global Solar Radiation for the Month of March 2016

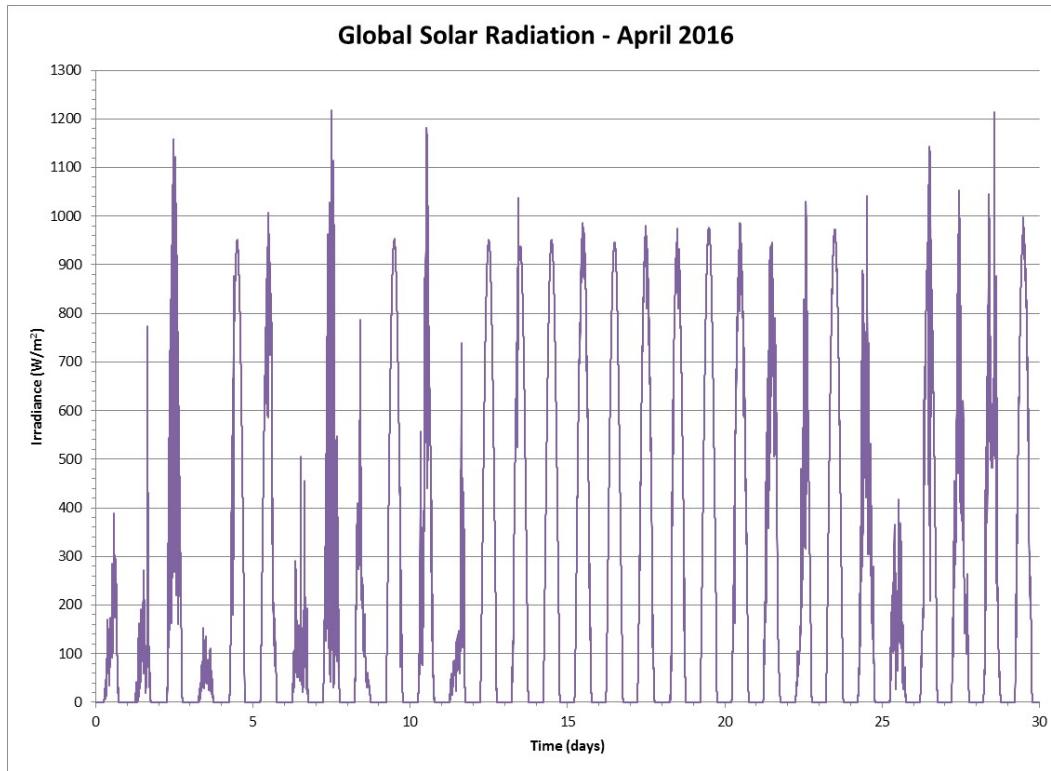


Figure 128 Global Solar Radiation for the Month of April 2016

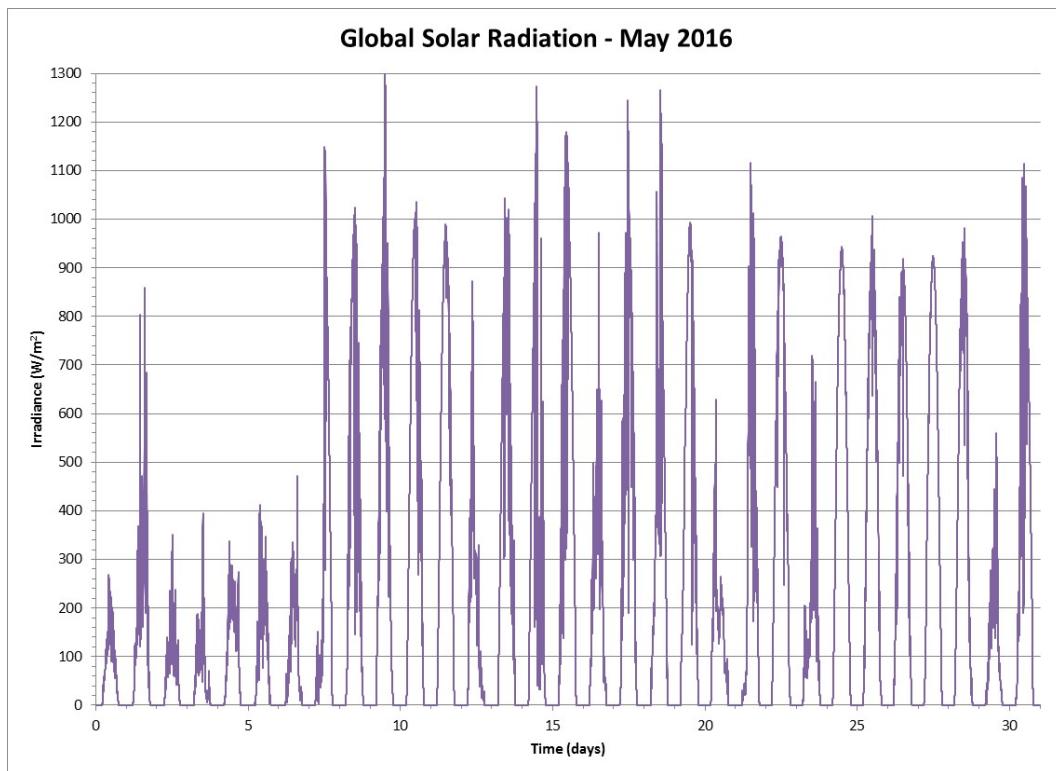


Figure 129 Global Solar Radiation for the Month of May 2016

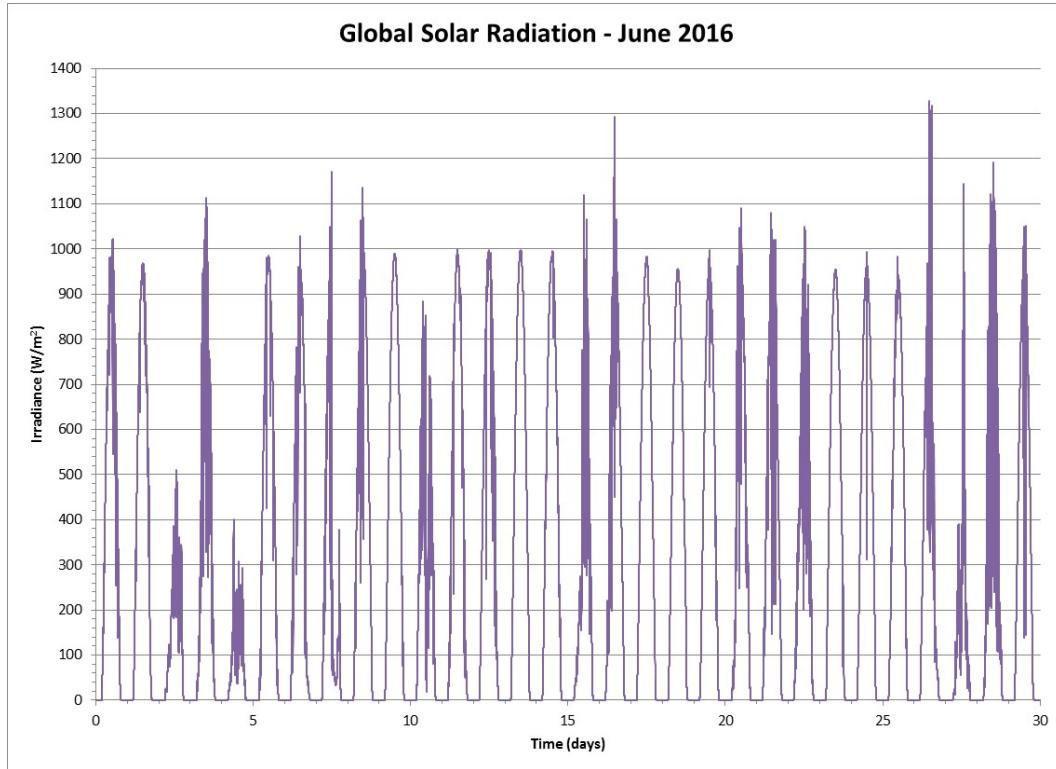


Figure 130 Global Solar Radiation for the Month of June 2016

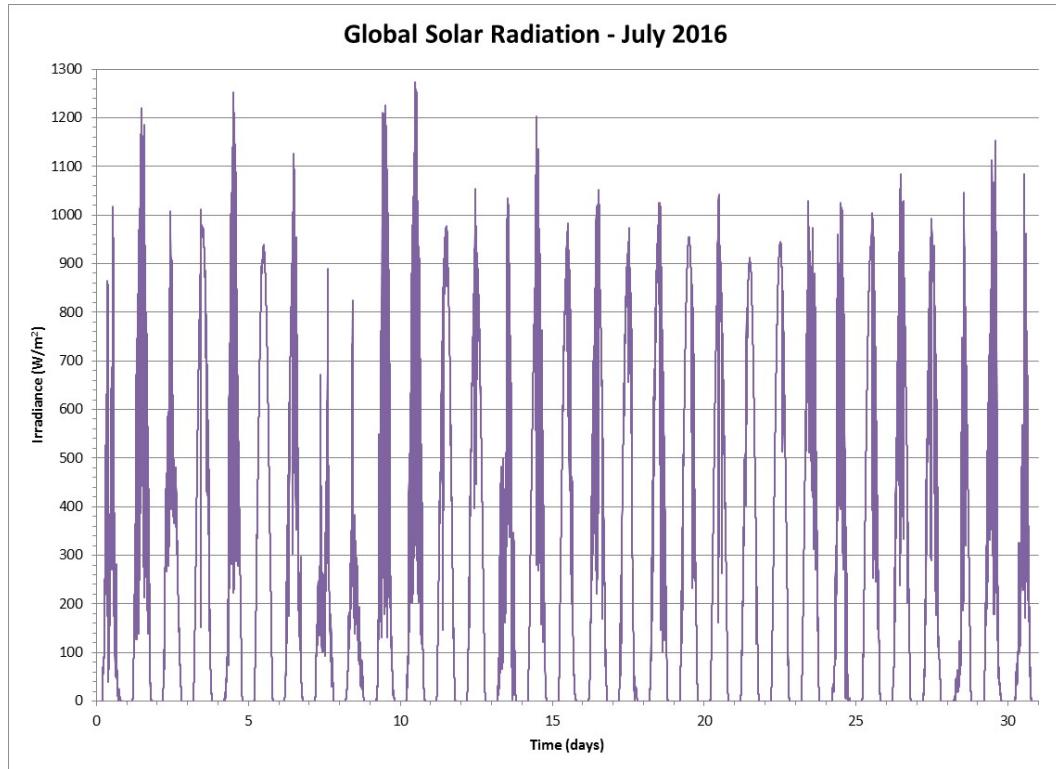


Figure 131 Global Solar Radiation for the Month of July 2016

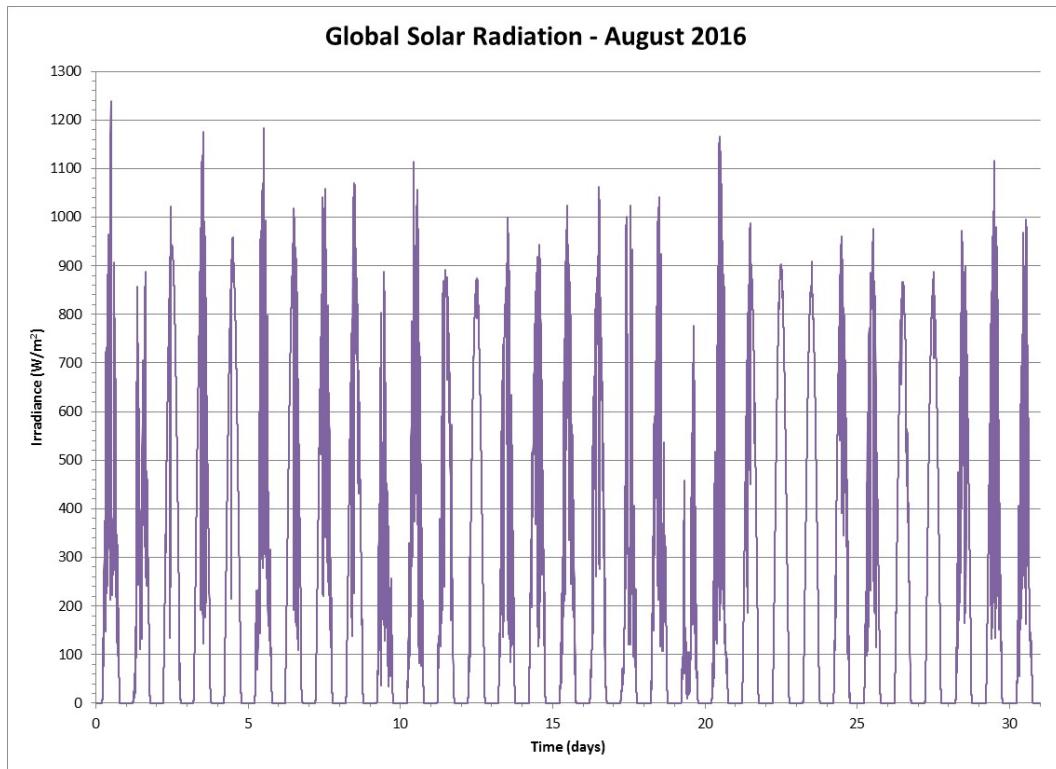


Figure 132 Global Solar Radiation for the Month of August 2016

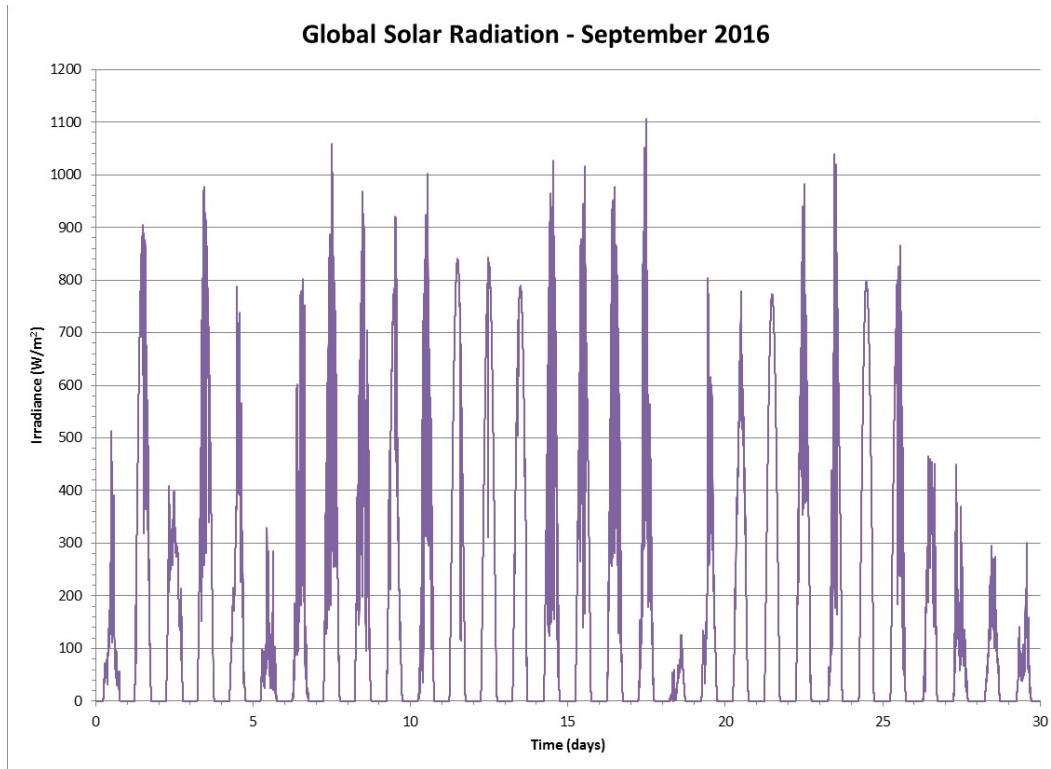


Figure 133 Global Solar Radiation for the Month of September 2016

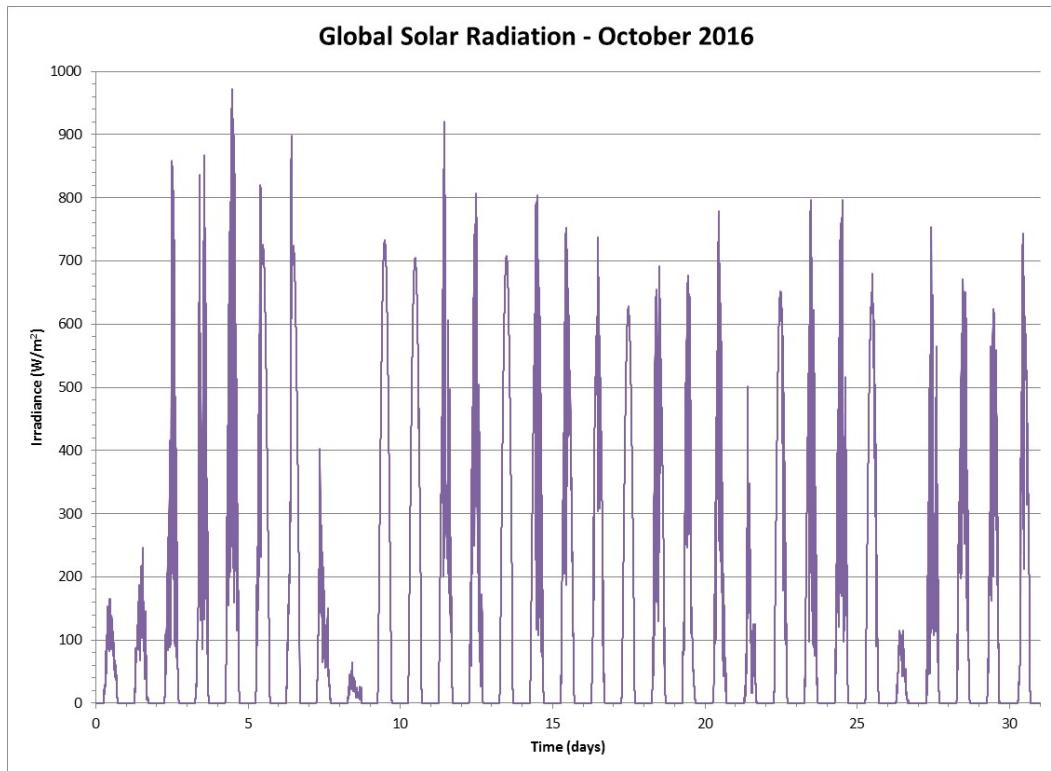


Figure 134 Global Solar Radiation for the Month of October 2016

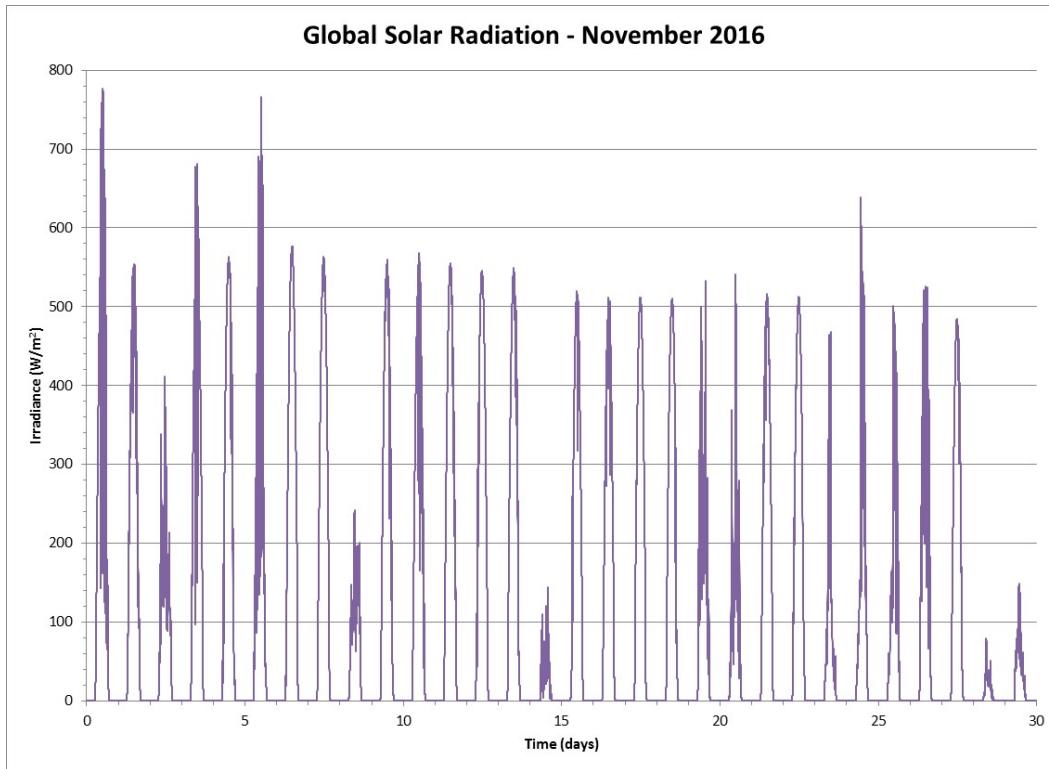


Figure 135 Global Solar Radiation for the Month of November 2016

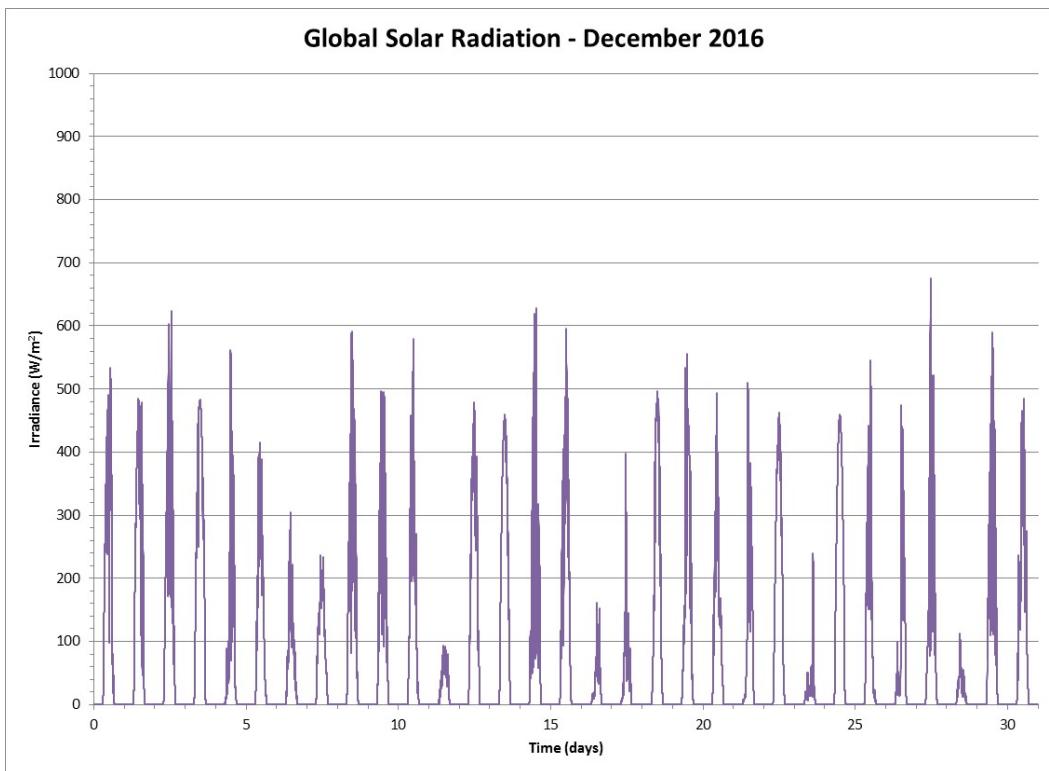


Figure 136 Global Solar Radiation for the Month of December 2016

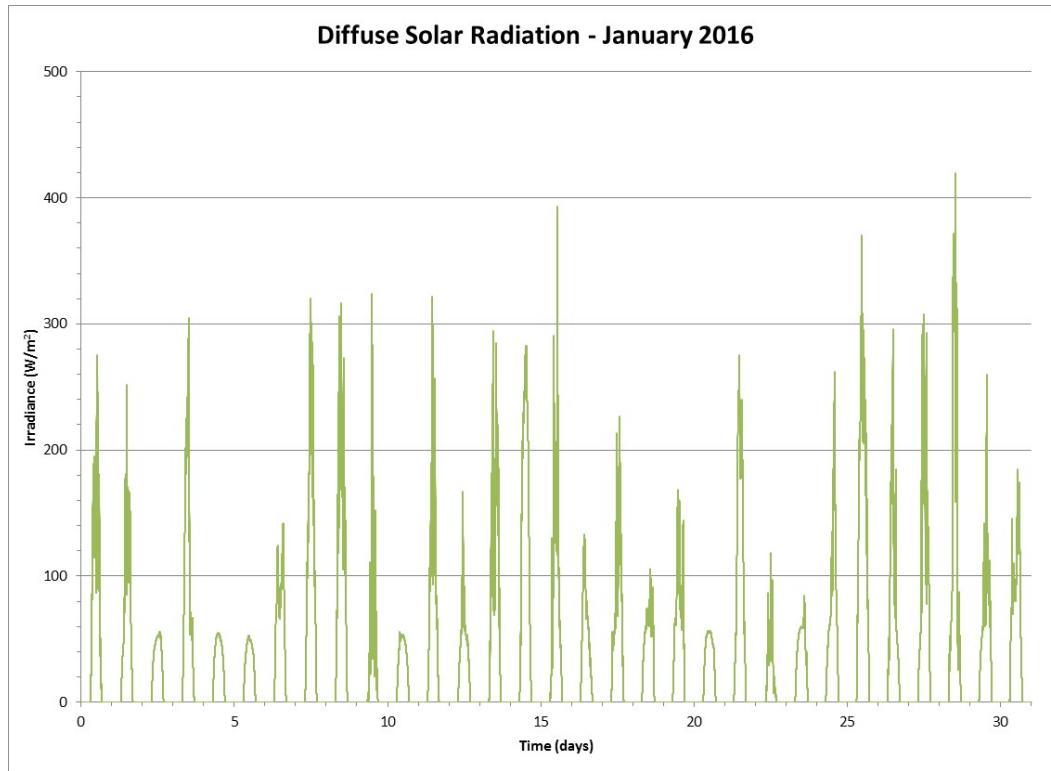


Figure 137 Diffuse Solar Radiation for the Month of January 2016

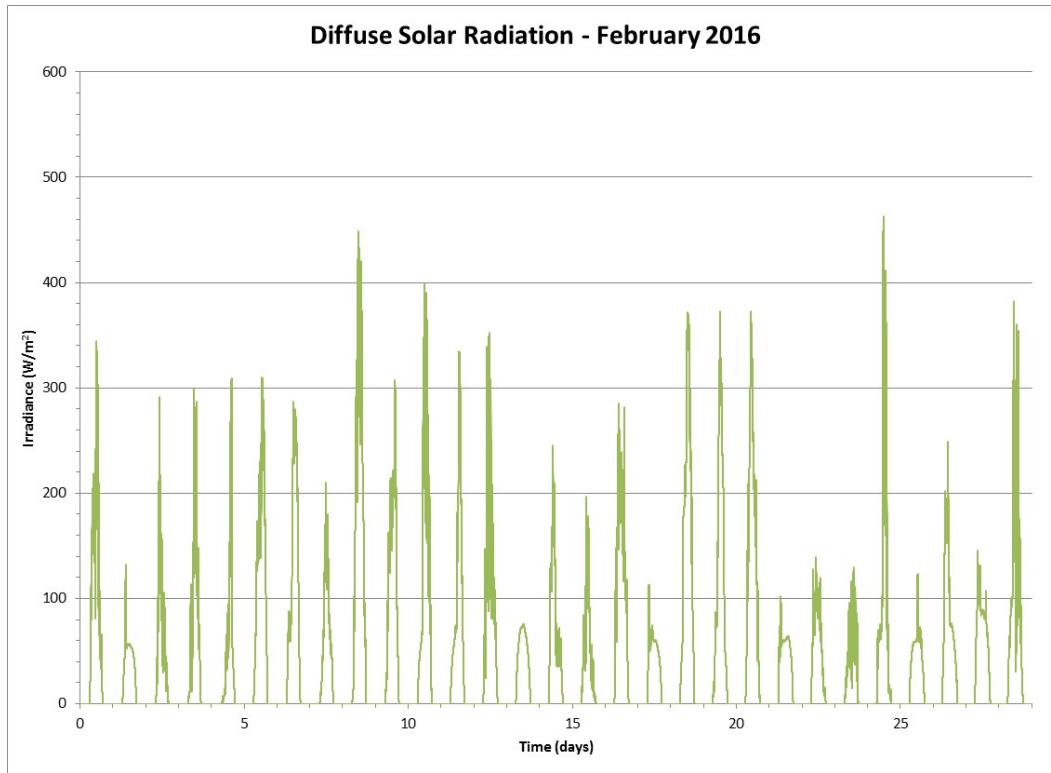


Figure 138 Diffuse Solar Radiation for the Month of February 2016

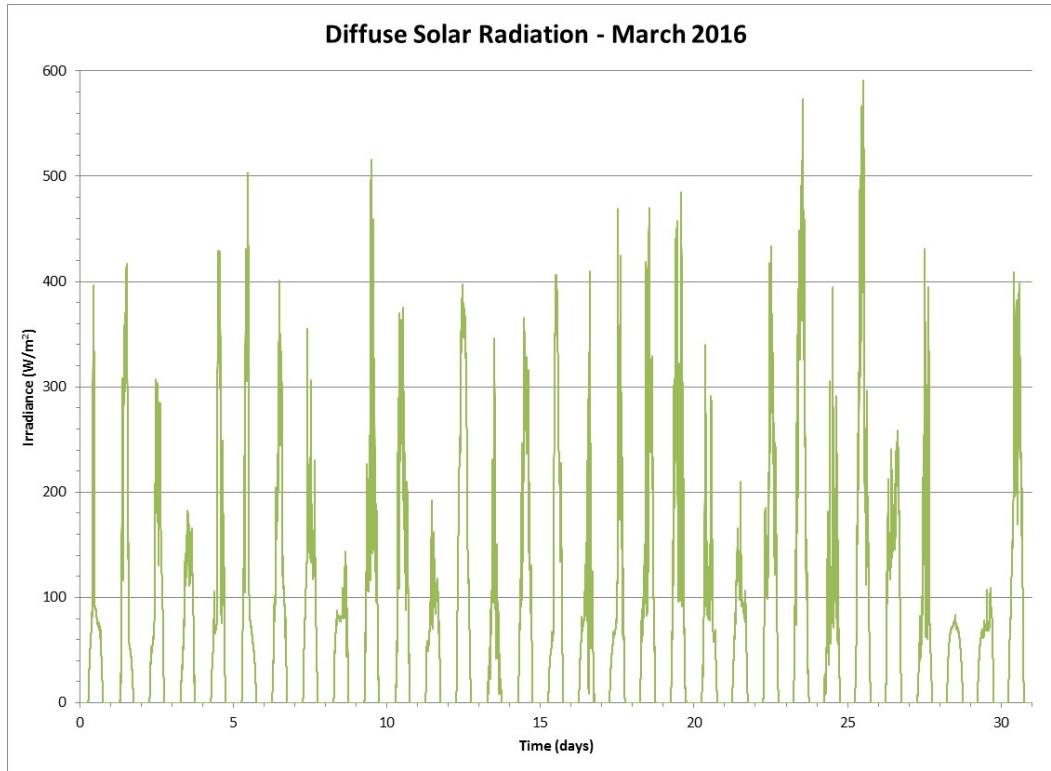


Figure 139 Diffuse Solar Radiation for the Month of March 2016

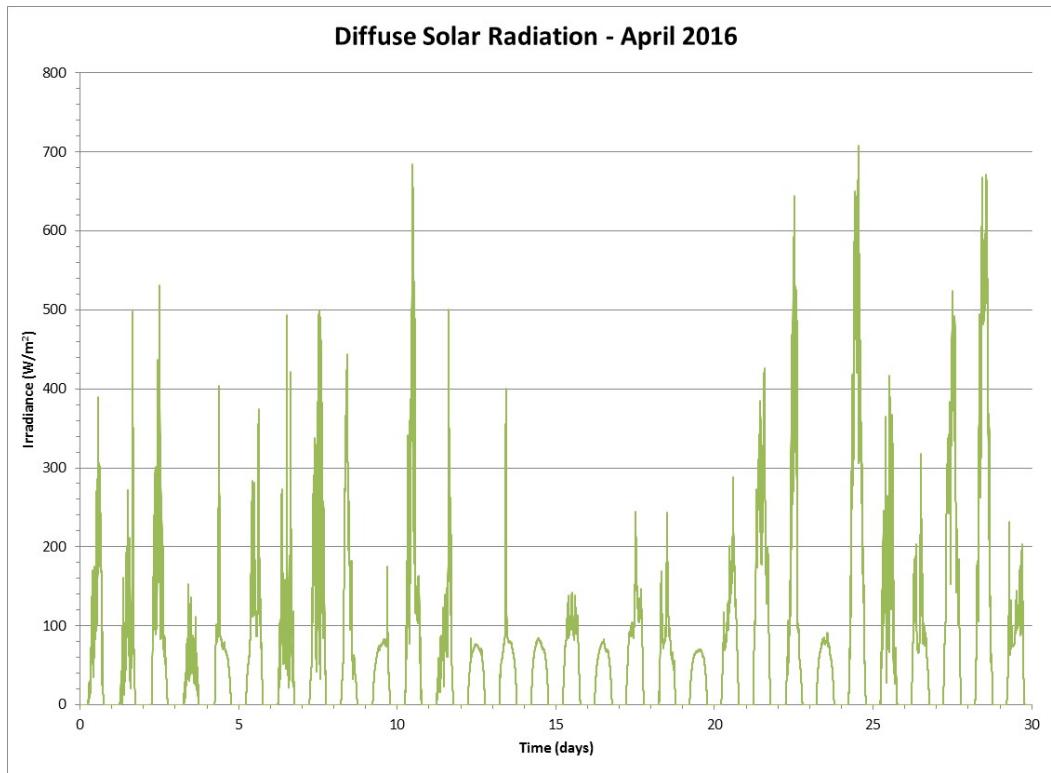


Figure 140 Diffuse Solar Radiation for the Month of April 2016

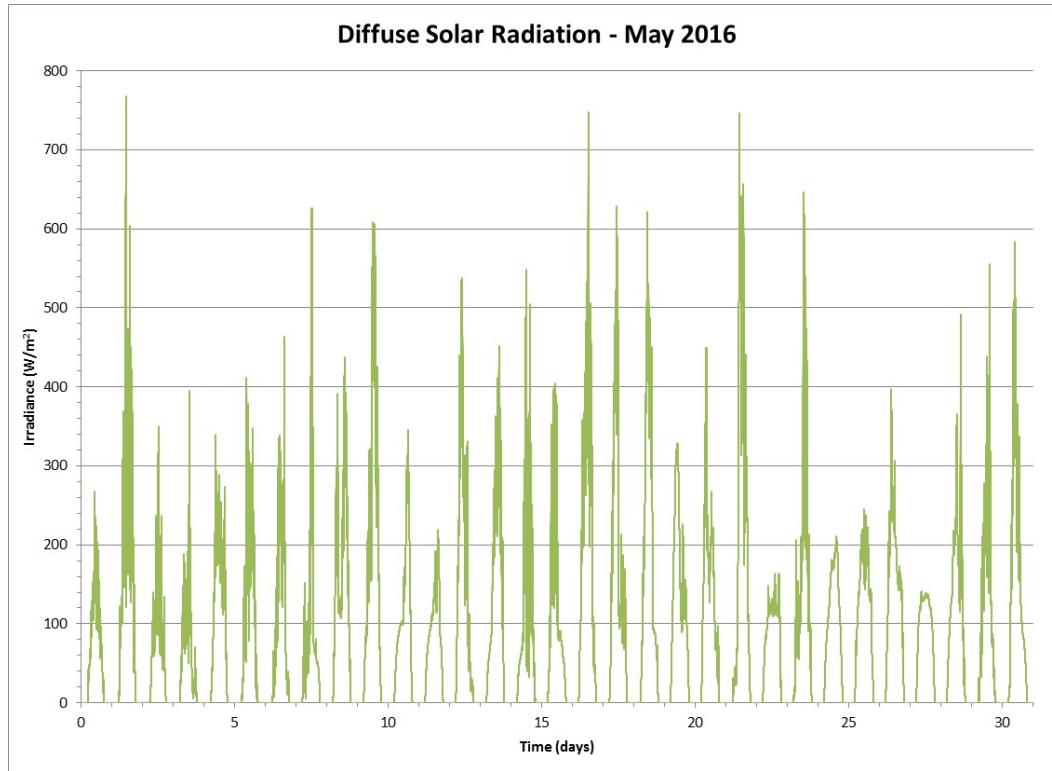


Figure 141 Diffuse Solar Radiation for the Month of May 2016

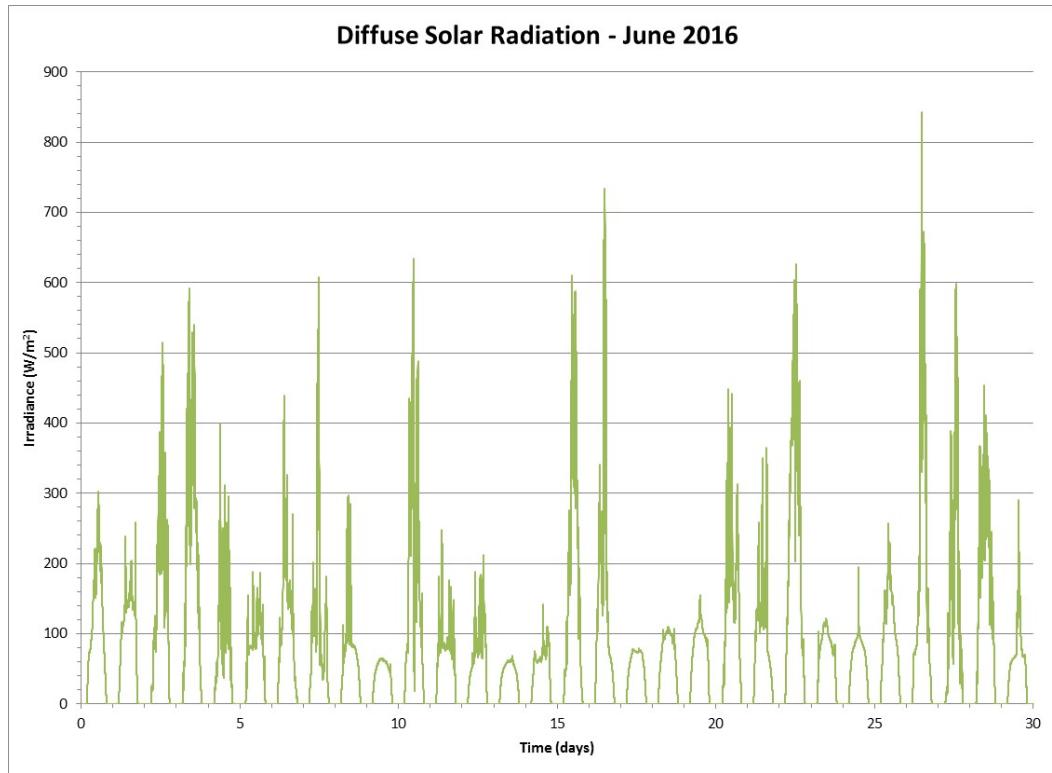


Figure 142 Diffuse Solar Radiation for the Month of June 2016

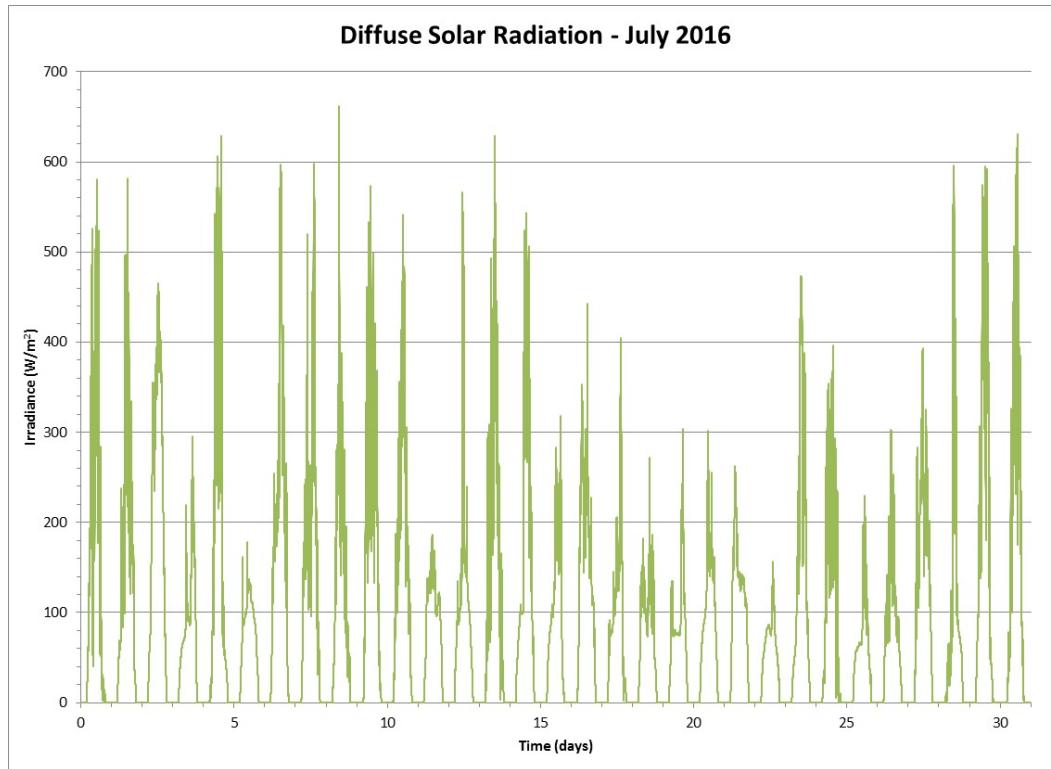


Figure 143 Diffuse Solar Radiation for the Month of July 2016

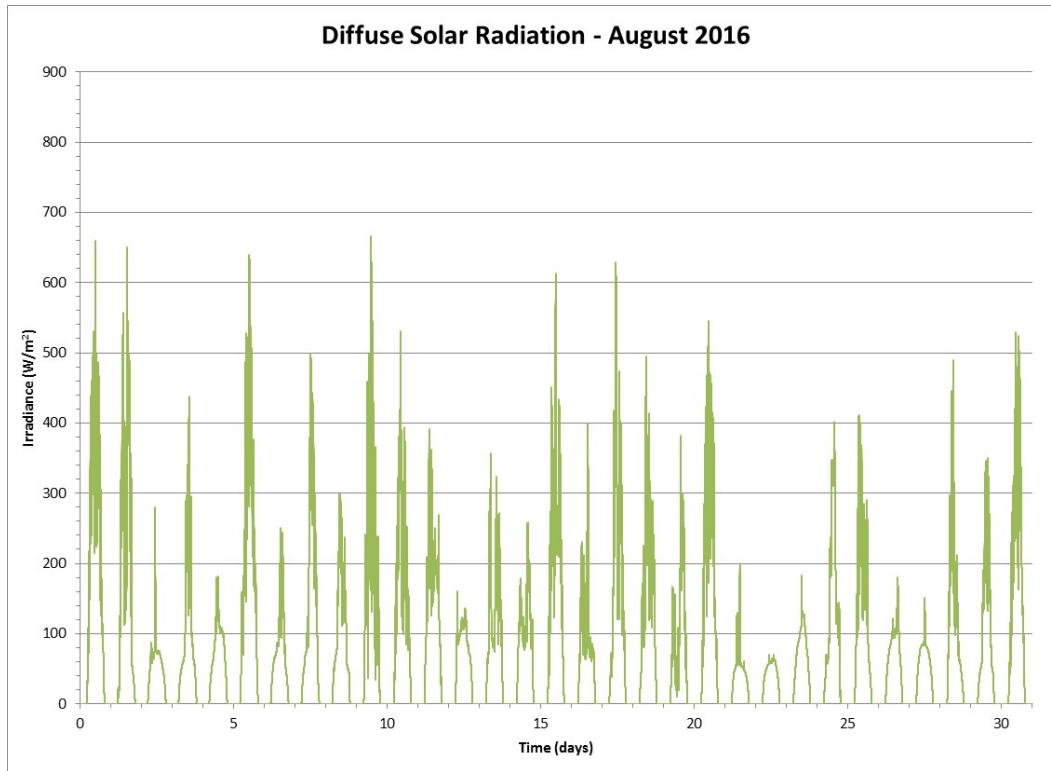


Figure 144 Diffuse Solar Radiation for the Month of August 2016

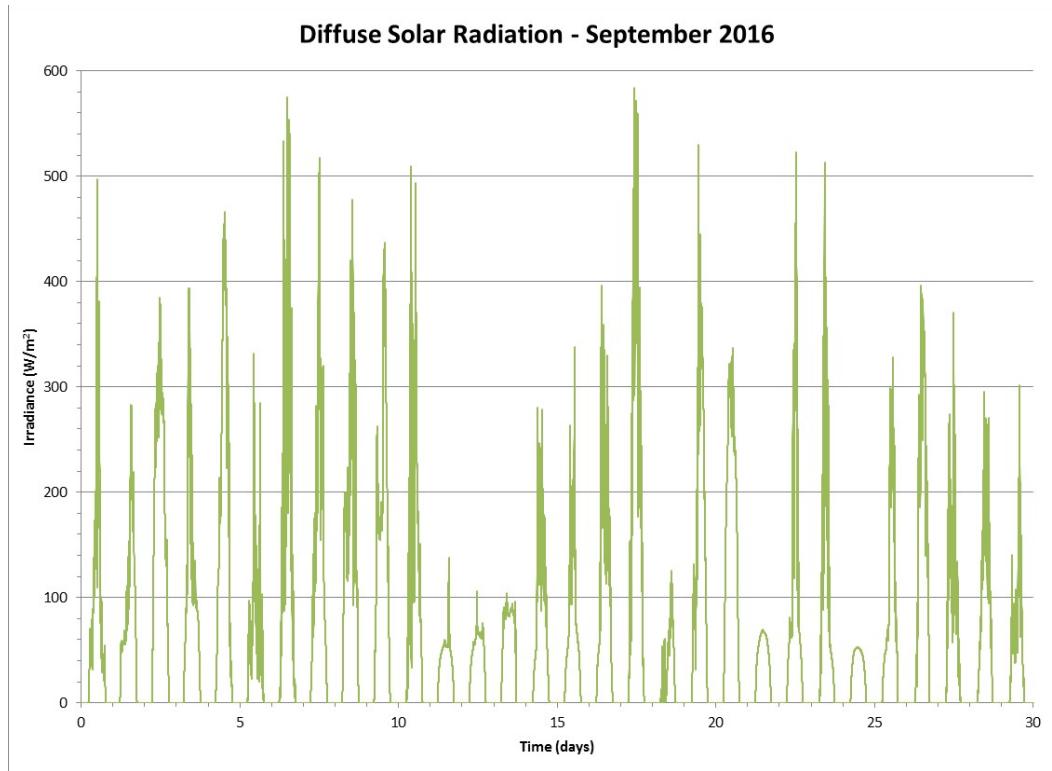


Figure 145 Diffuse Solar Radiation for the Month of September 2016

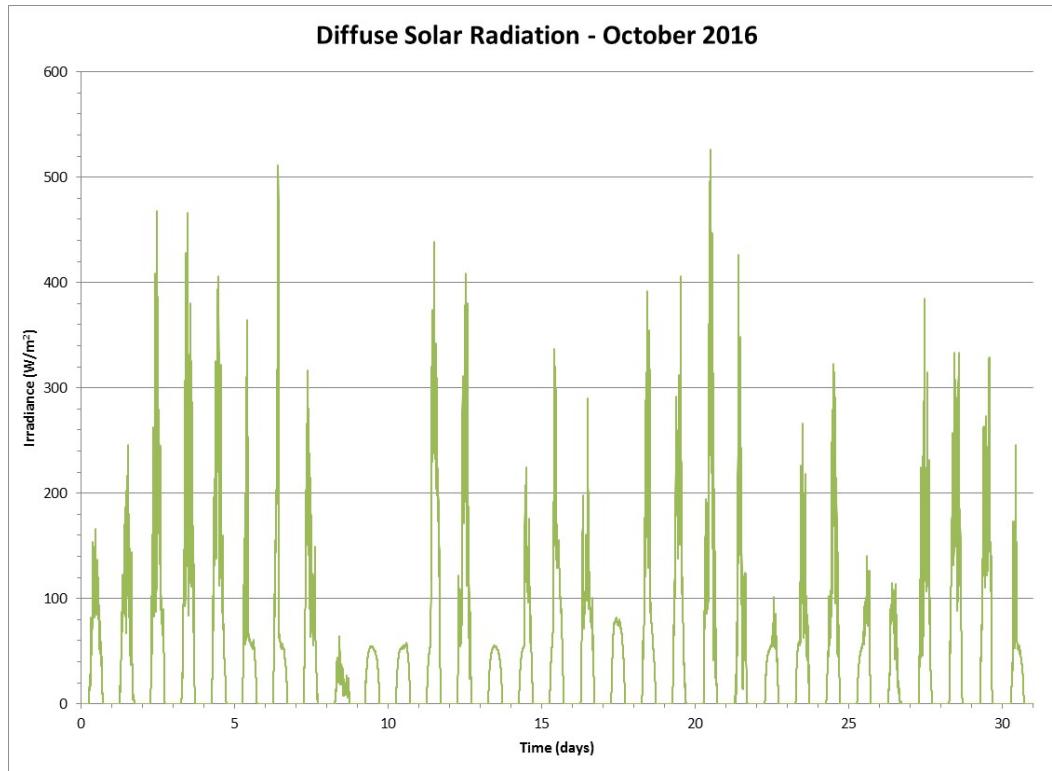


Figure 146 Diffuse Solar Radiation for the Month of October 2016

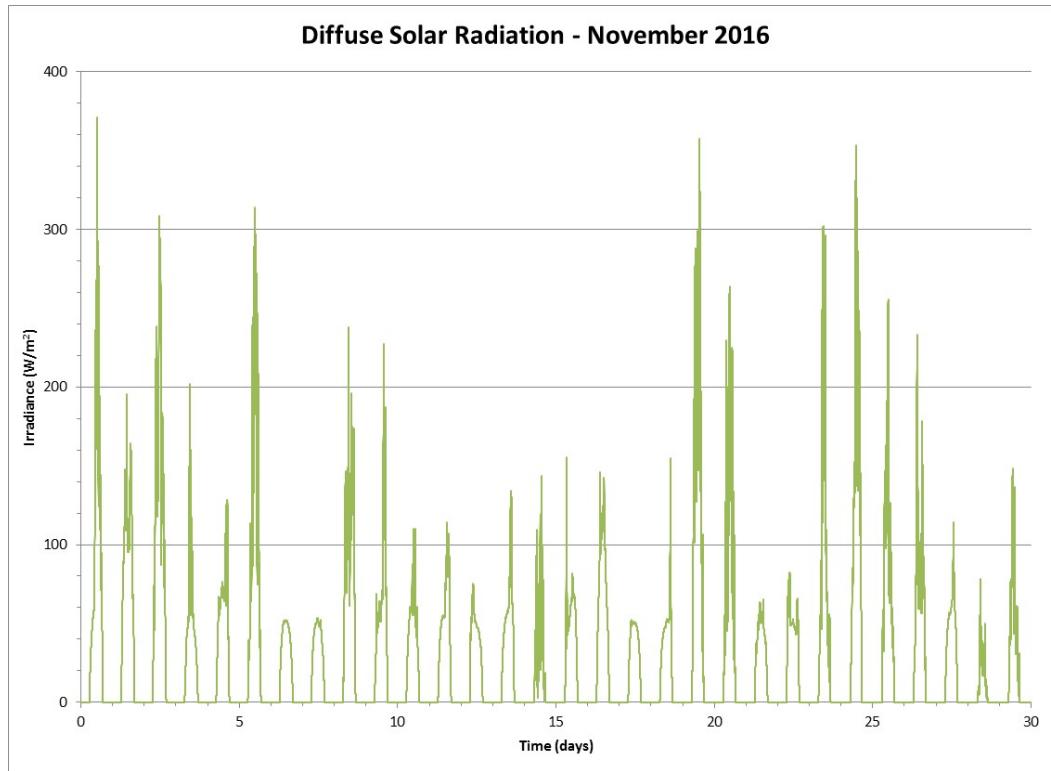


Figure 147 Diffuse Solar Radiation for the Month of November 2016

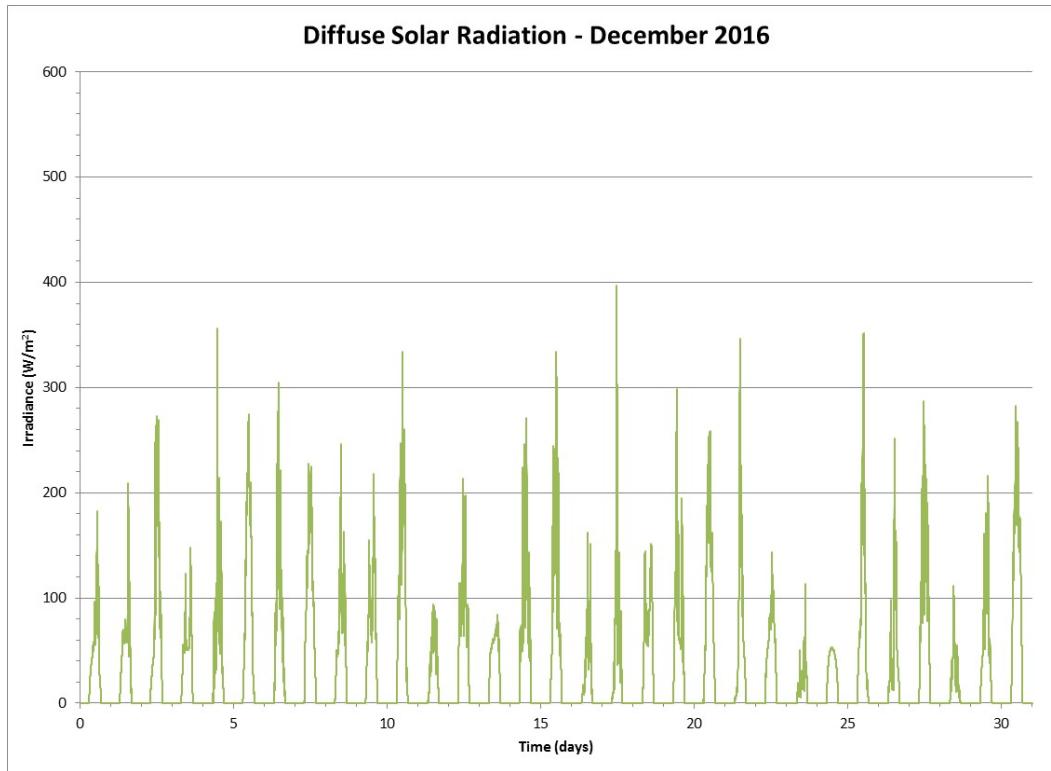


Figure 148 Diffuse Solar Radiation for the Month of December 2016

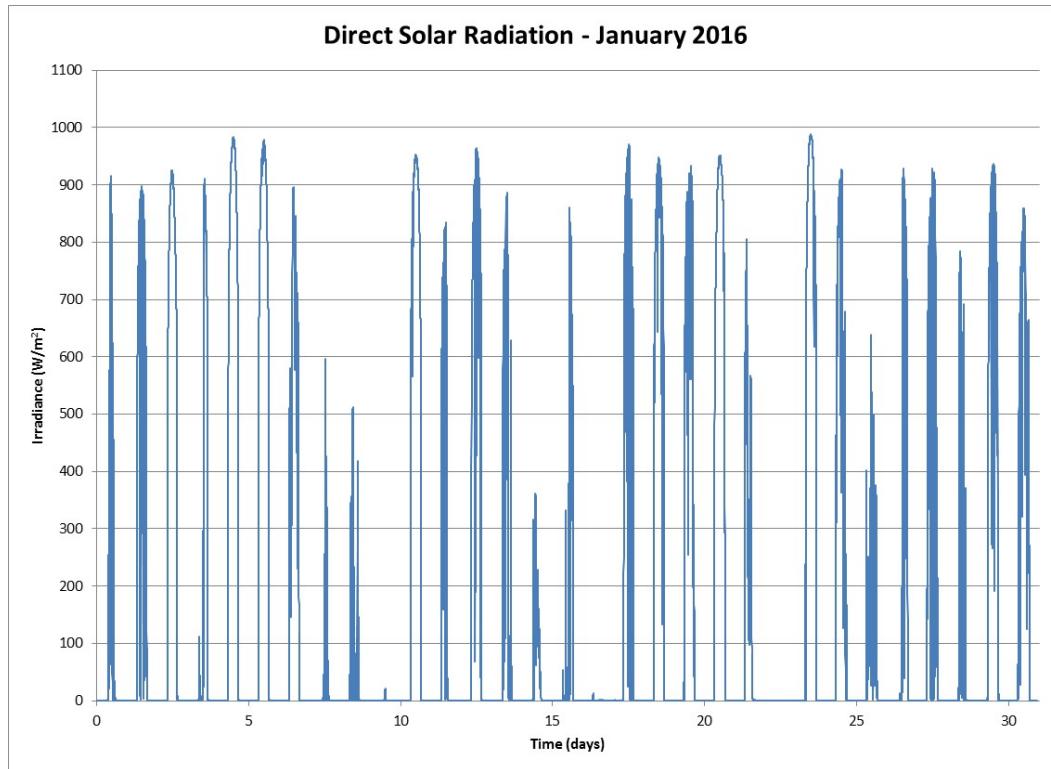


Figure 149 Direct Solar Radiation for the Month of January 2016

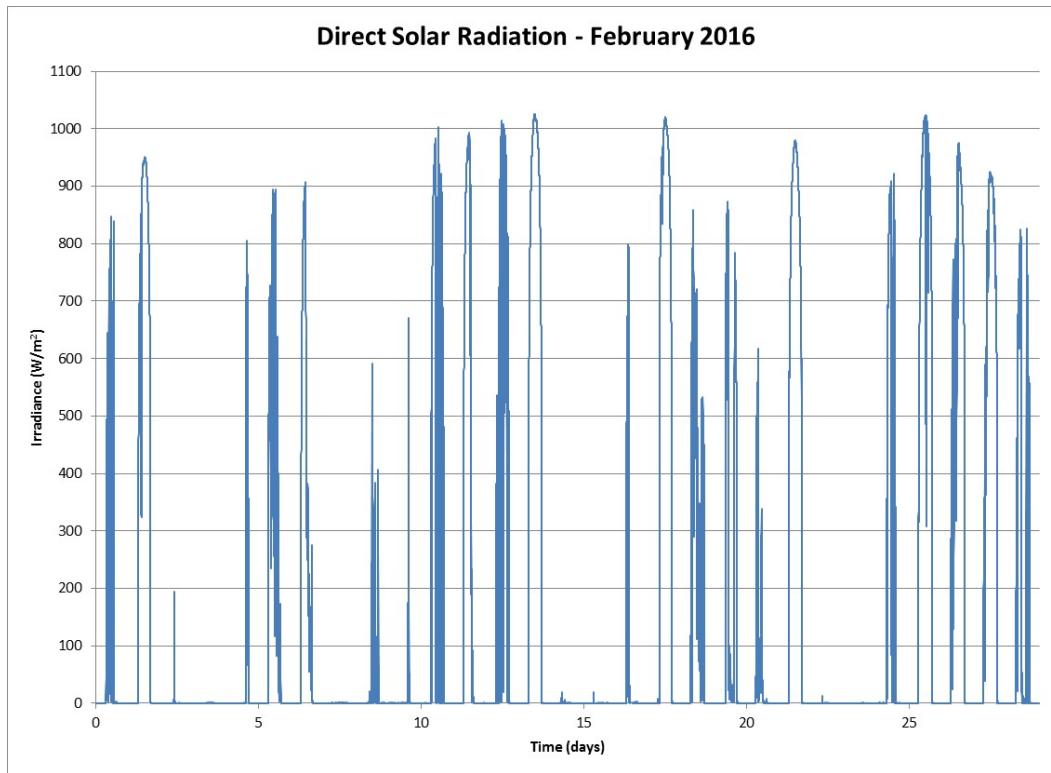


Figure 150 Direct Solar Radiation for the Month of February 2016

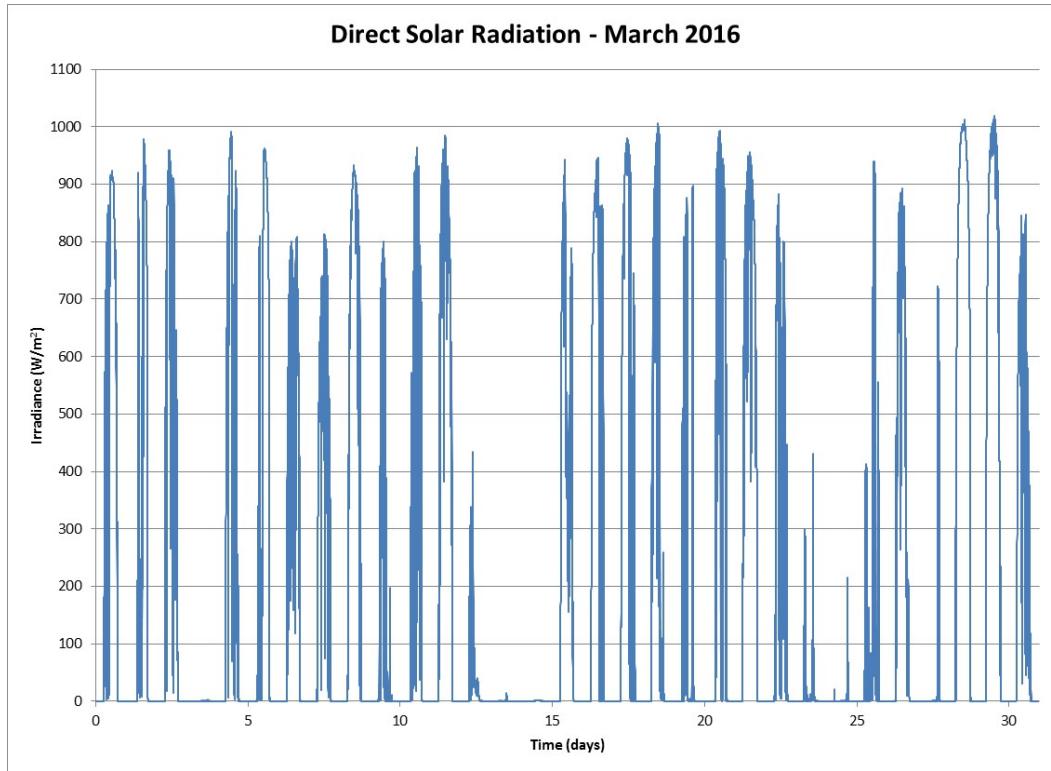


Figure 151 Direct Solar Radiation for the Month of March 2016

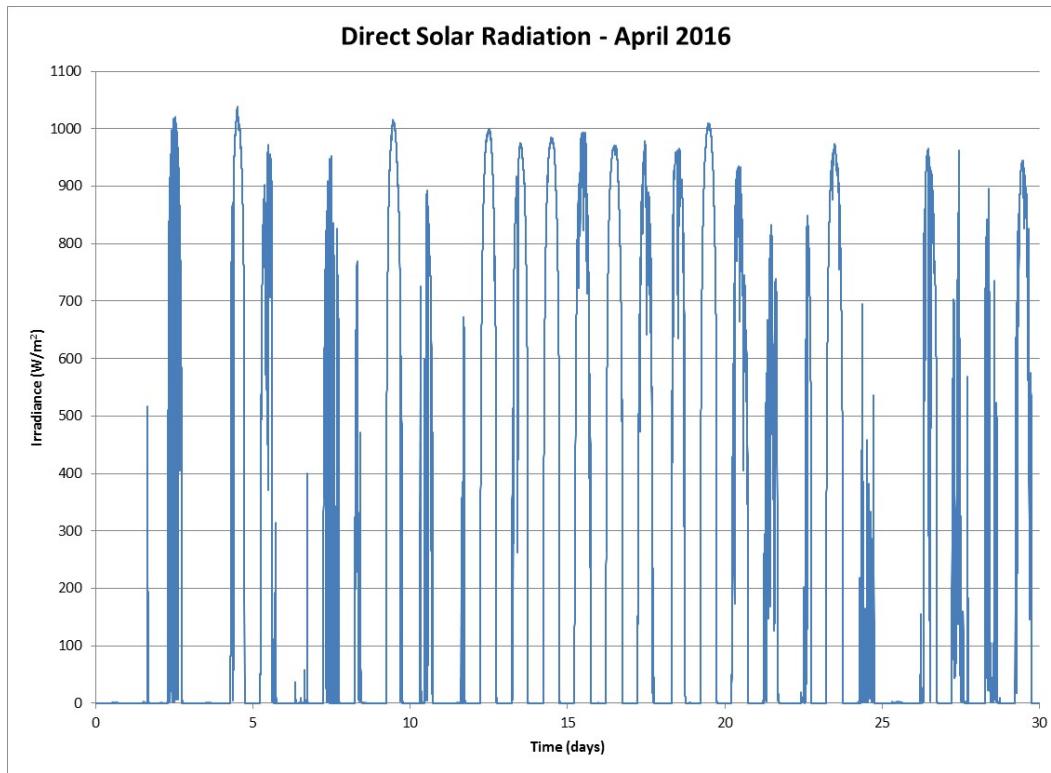


Figure 152 Direct Solar Radiation for the Month April 2016

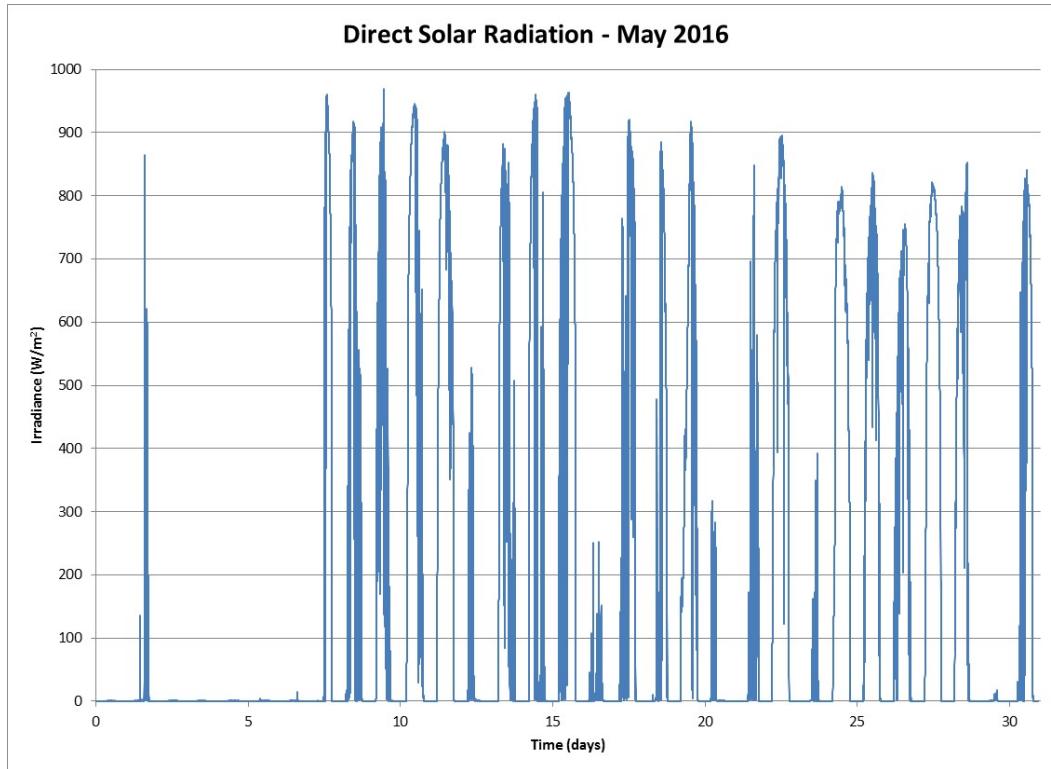


Figure 153 Direct Solar Radiation for the Month May 2016

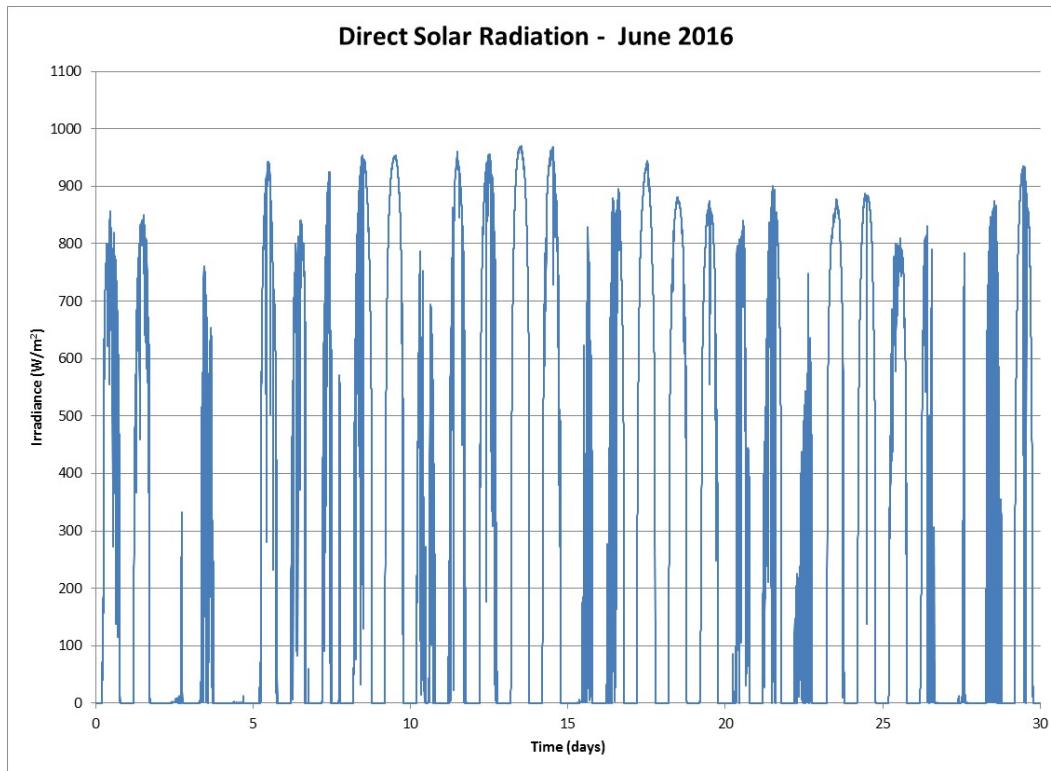


Figure 154 Direct Solar Radiation for the Month June 2016

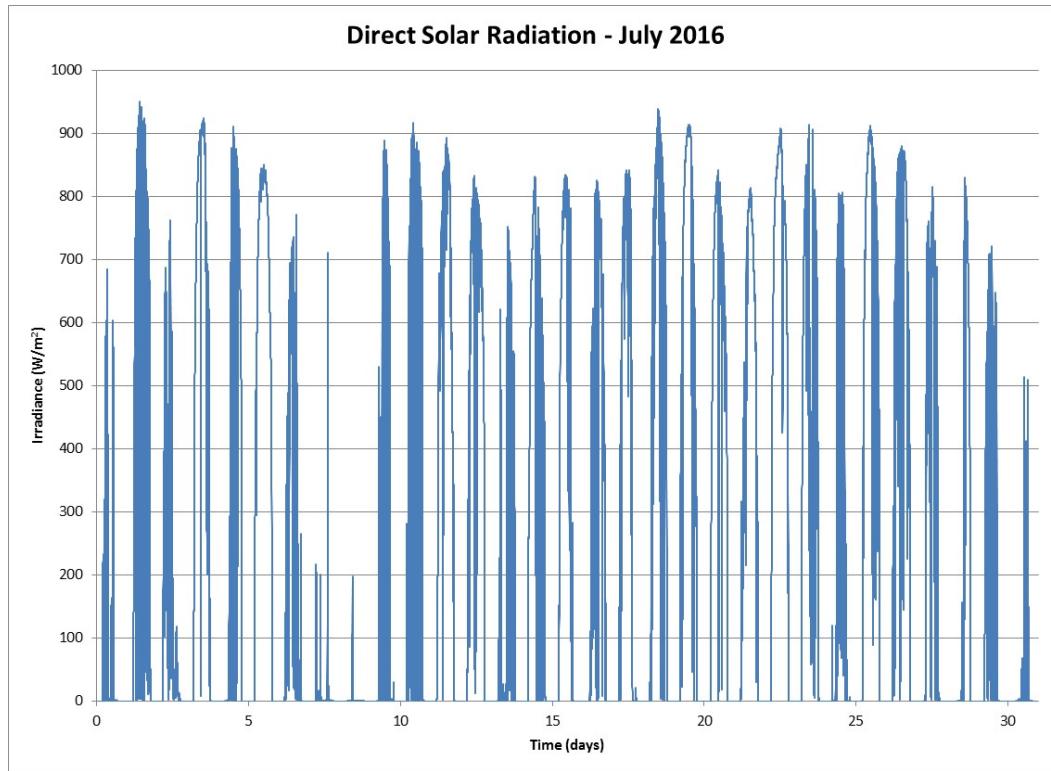


Figure 155 Direct Solar Radiation for the Month July 2016

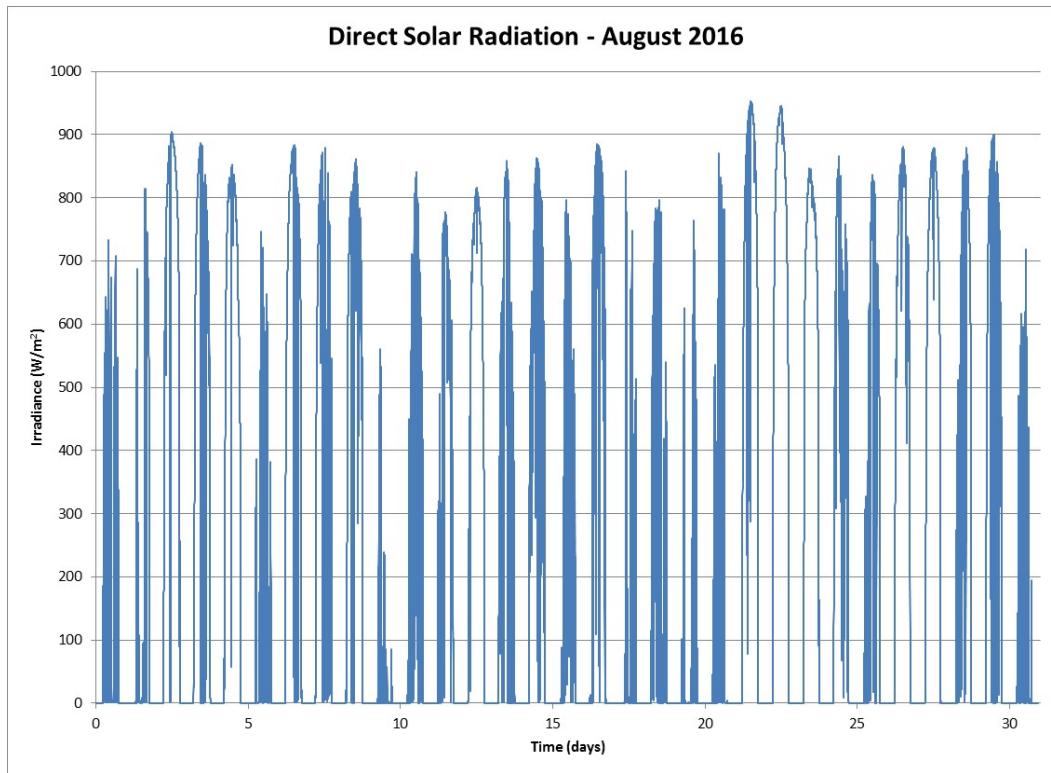


Figure 156 Direct Solar Radiation for the Month August 2016

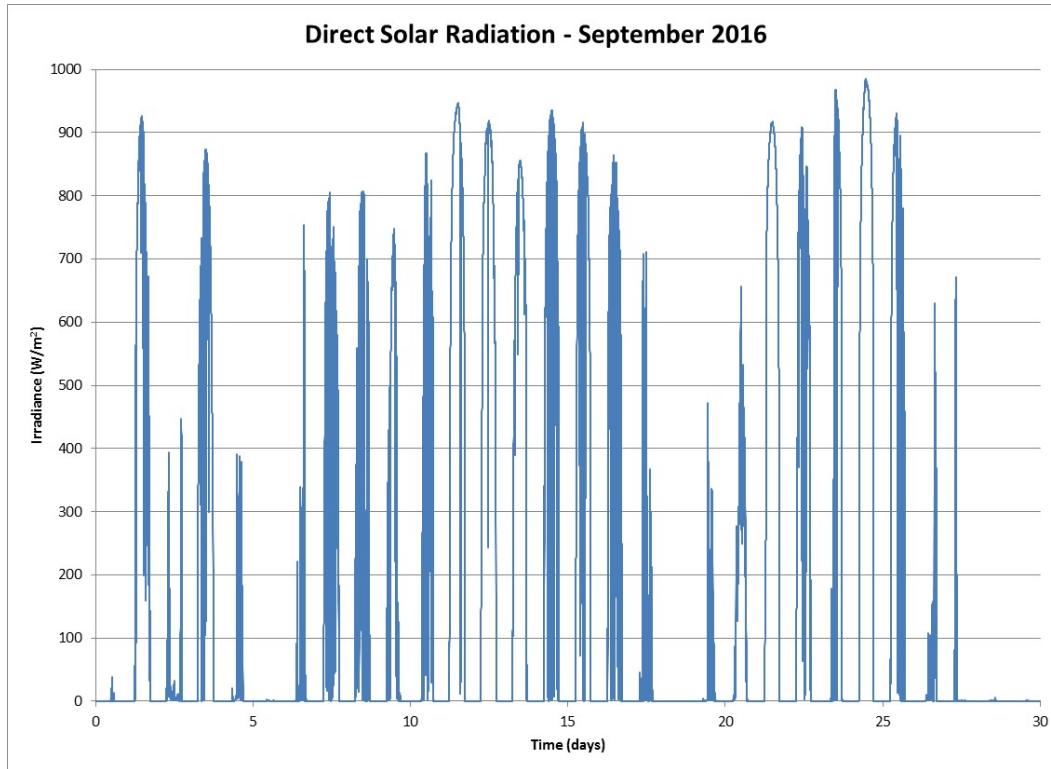


Figure 157 Direct Solar Radiation for the Month September 2016

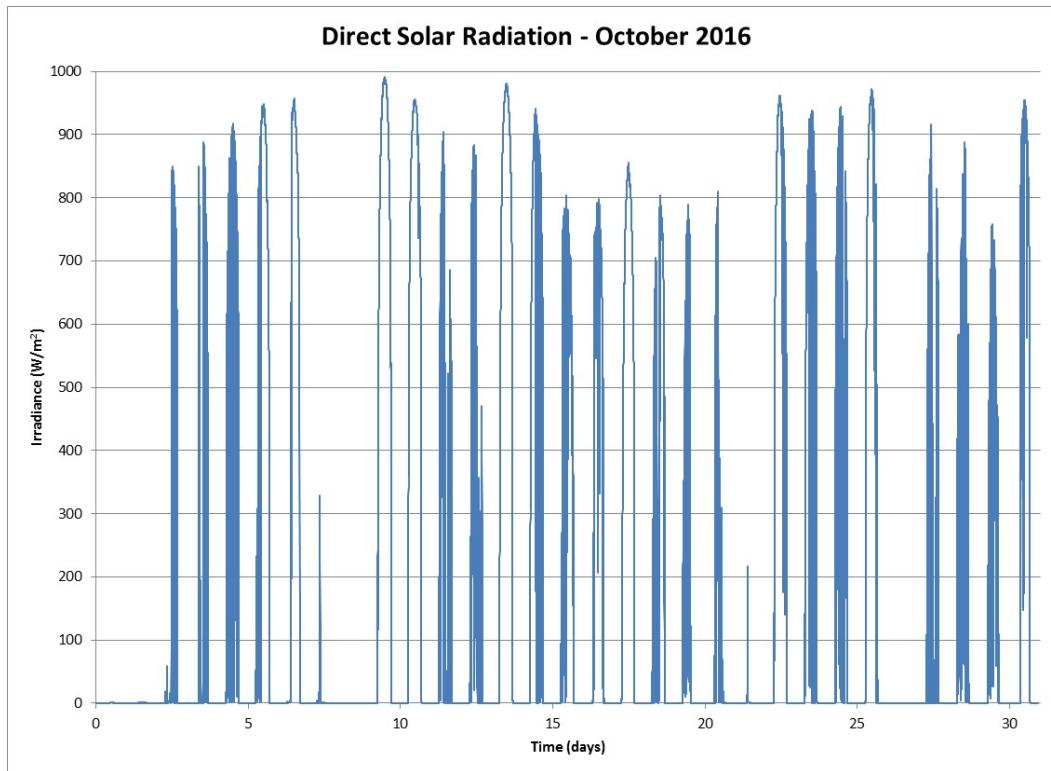


Figure 158 Direct Solar Radiation for the Month October 2016

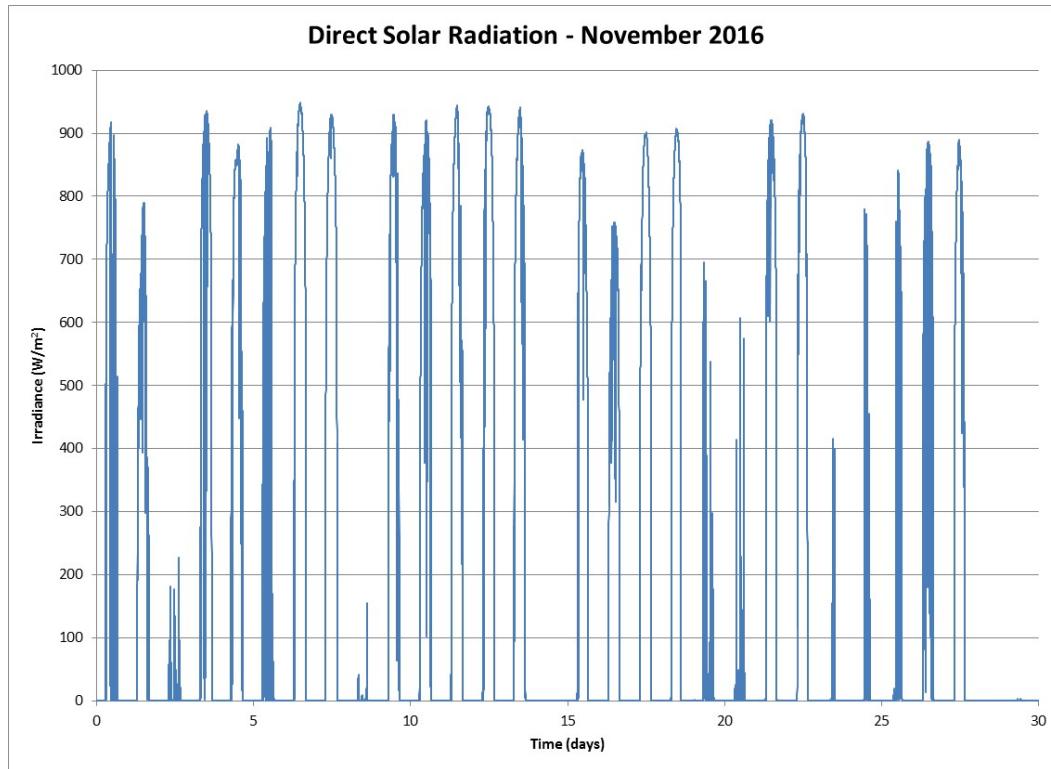


Figure 159 Direct Solar Radiation for the Month November 2016

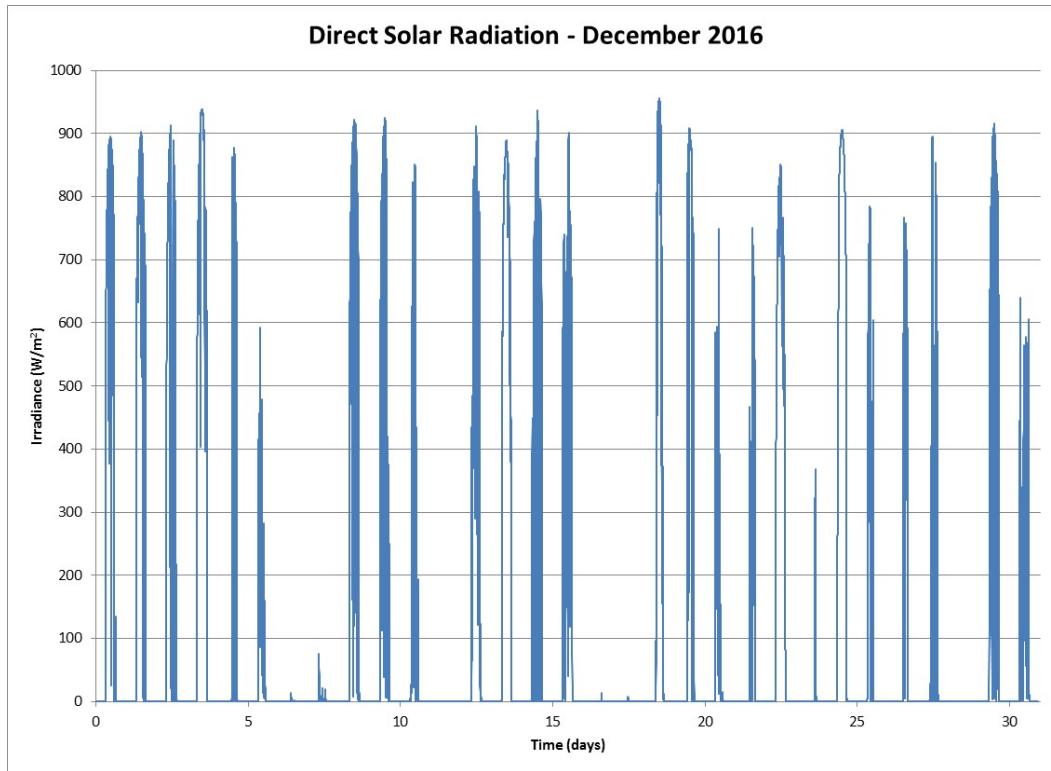


Figure 160 Direct Solar Radiation for the Month December 2016

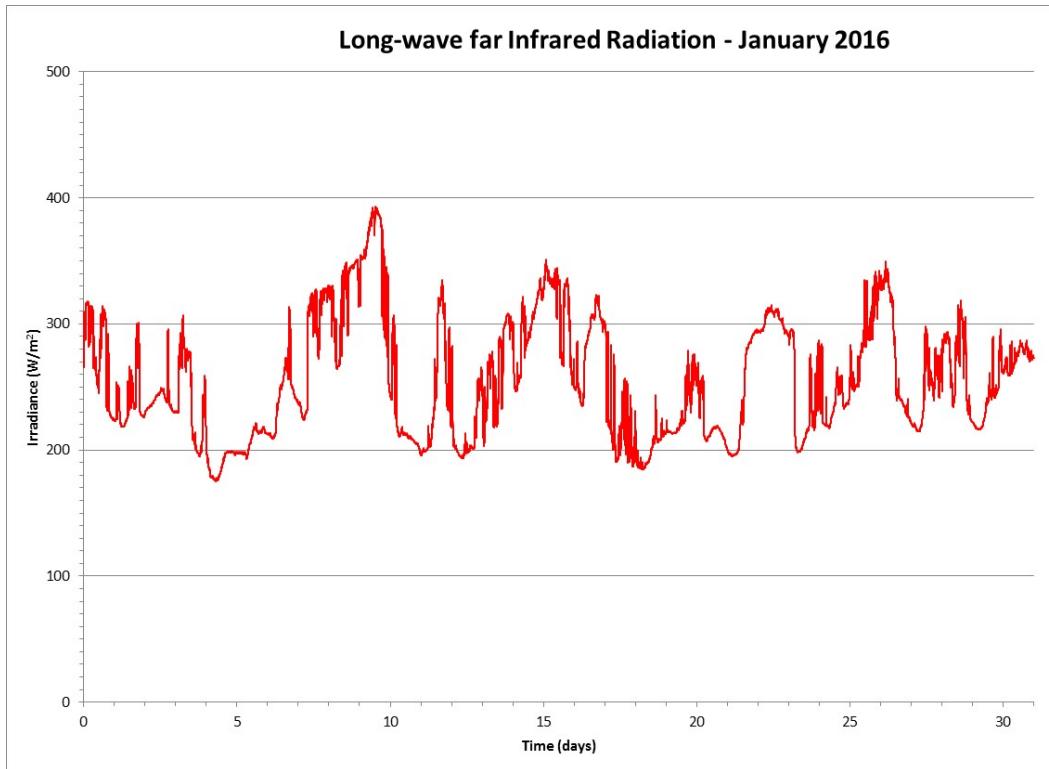


Figure 161 Long-wave Far Infrared Radiation for the Month of January 2016

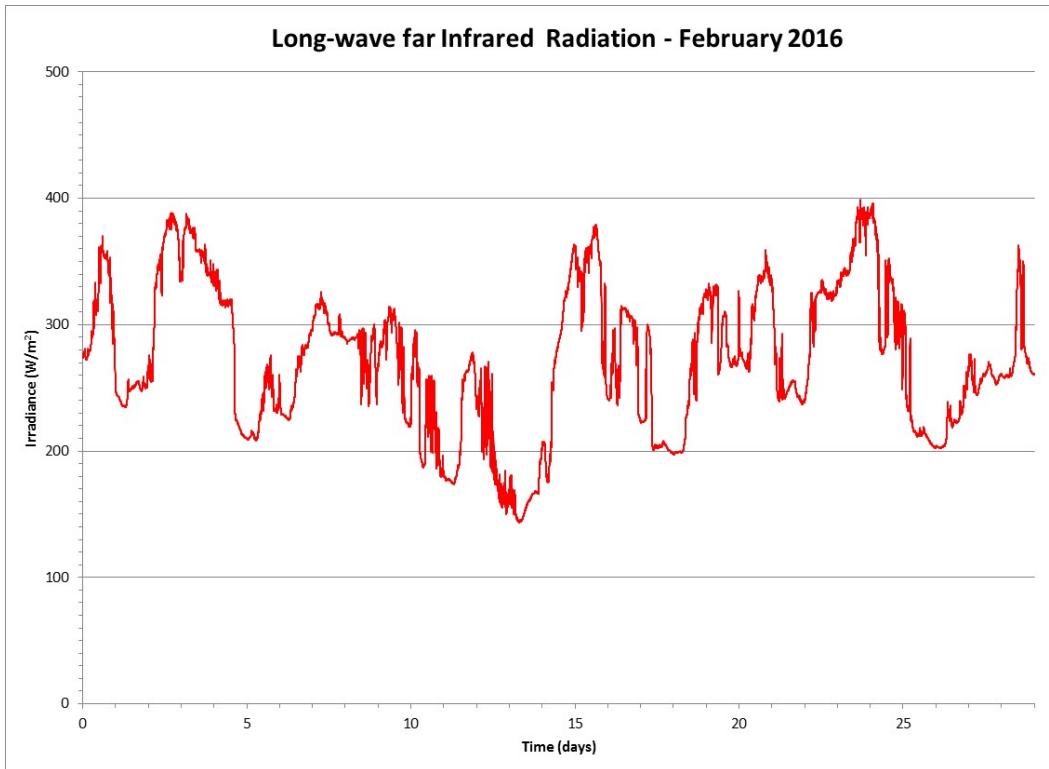


Figure 162 Long-wave Far Infrared Radiation for the Month of February 2016

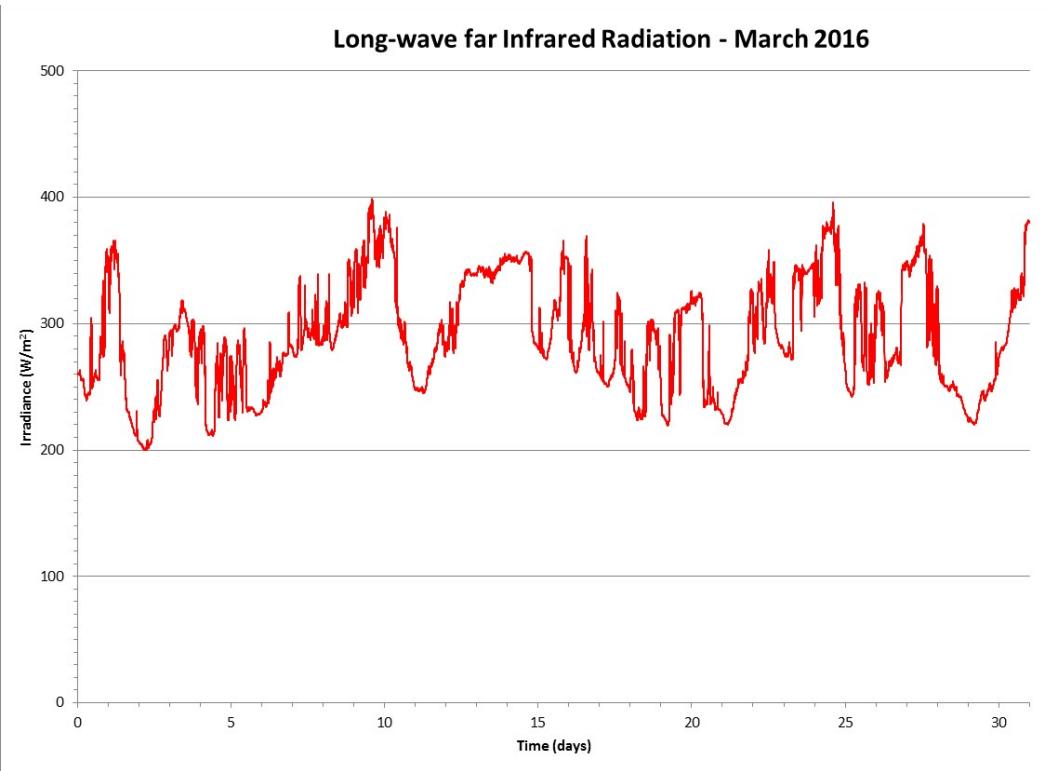


Figure 163 Long-wave Far Infrared Radiation for the Month of March 2016

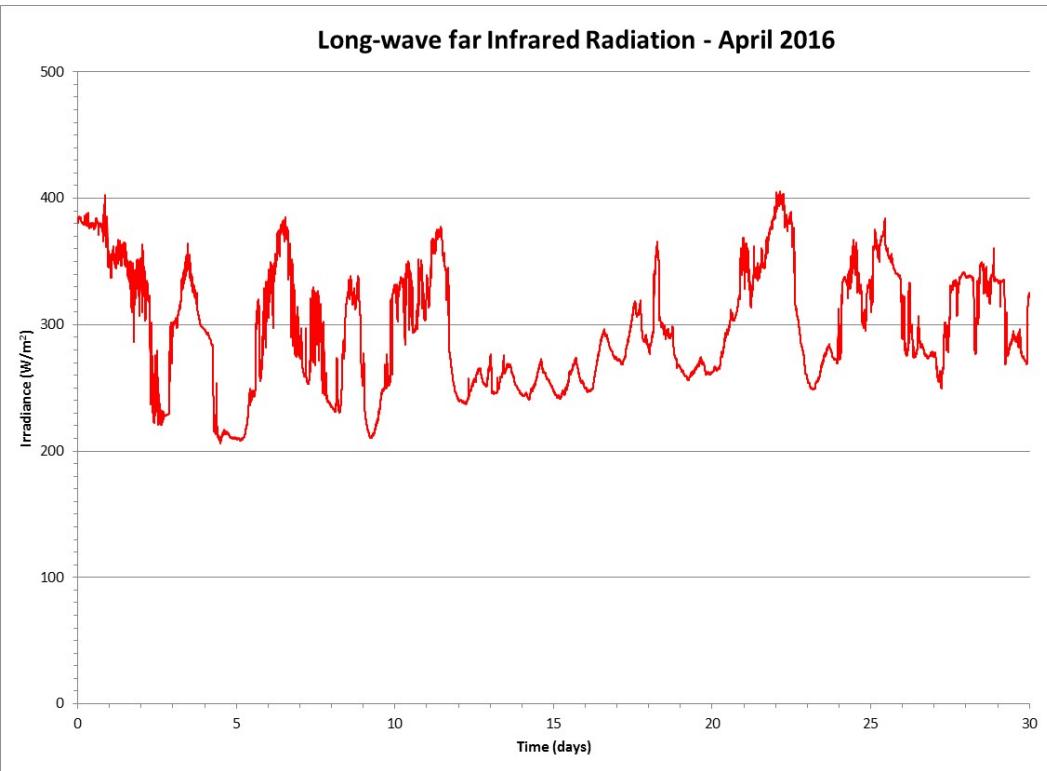


Figure 164 Long-wave Far Infrared Radiation for the Month of April 2016

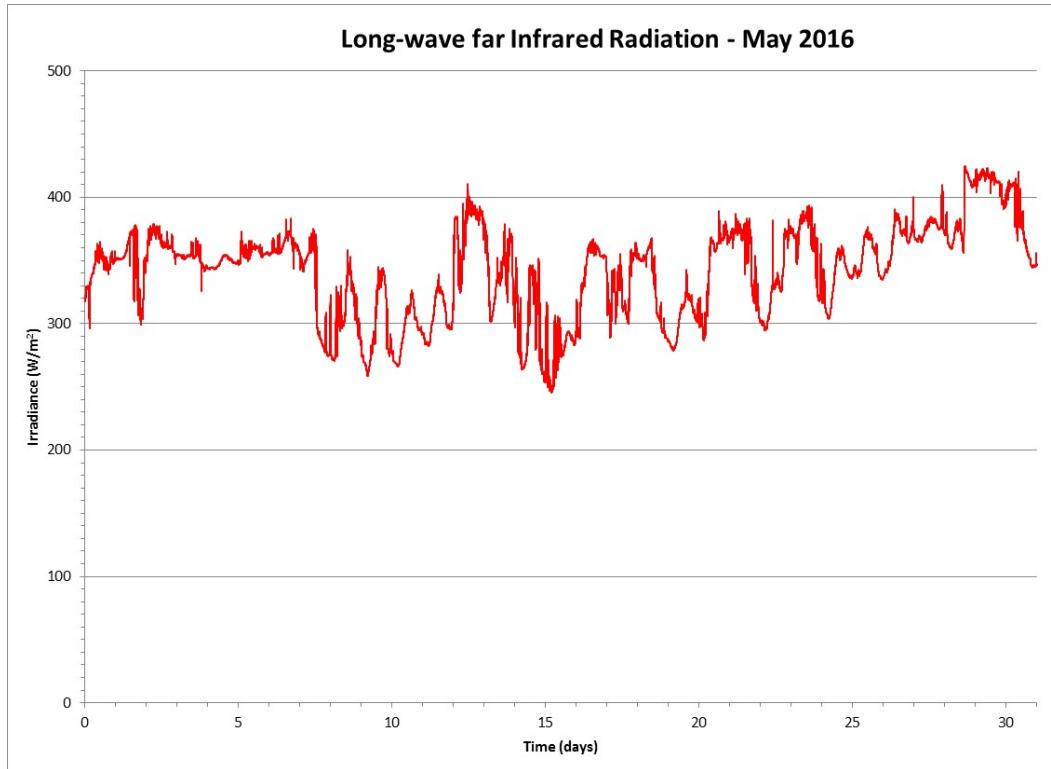


Figure 165 Long-wave Far Infrared Radiation for the Month of May 2016

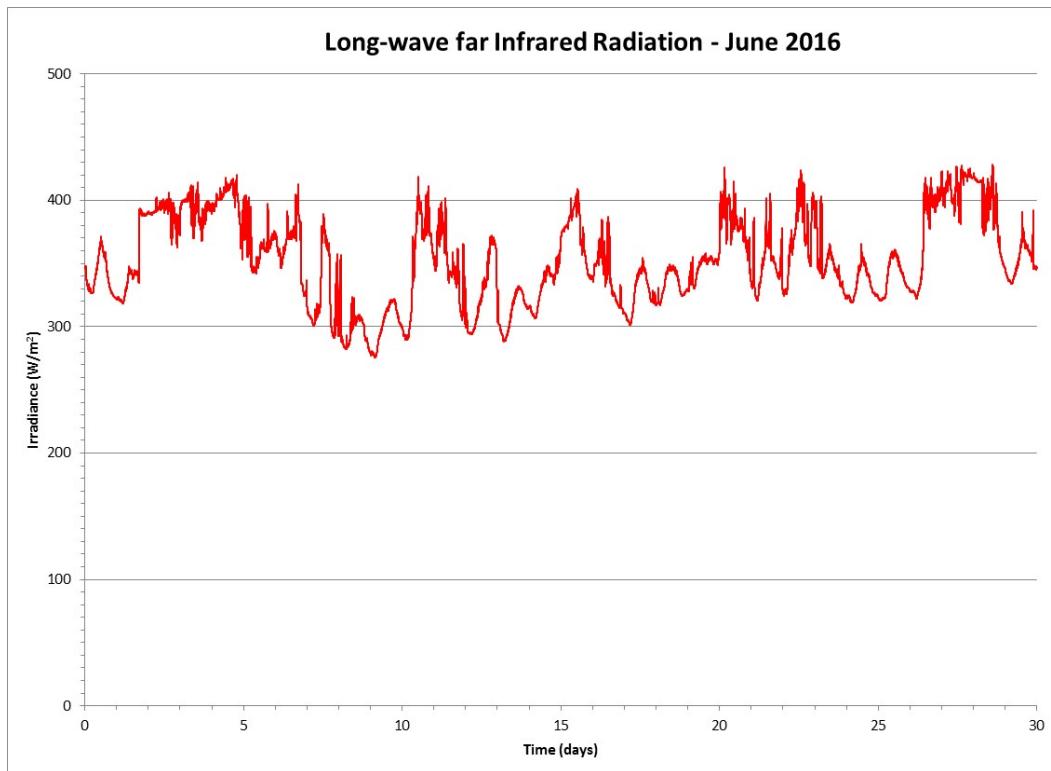


Figure 166 Long-wave Far Infrared Radiation for the Month of June 2016

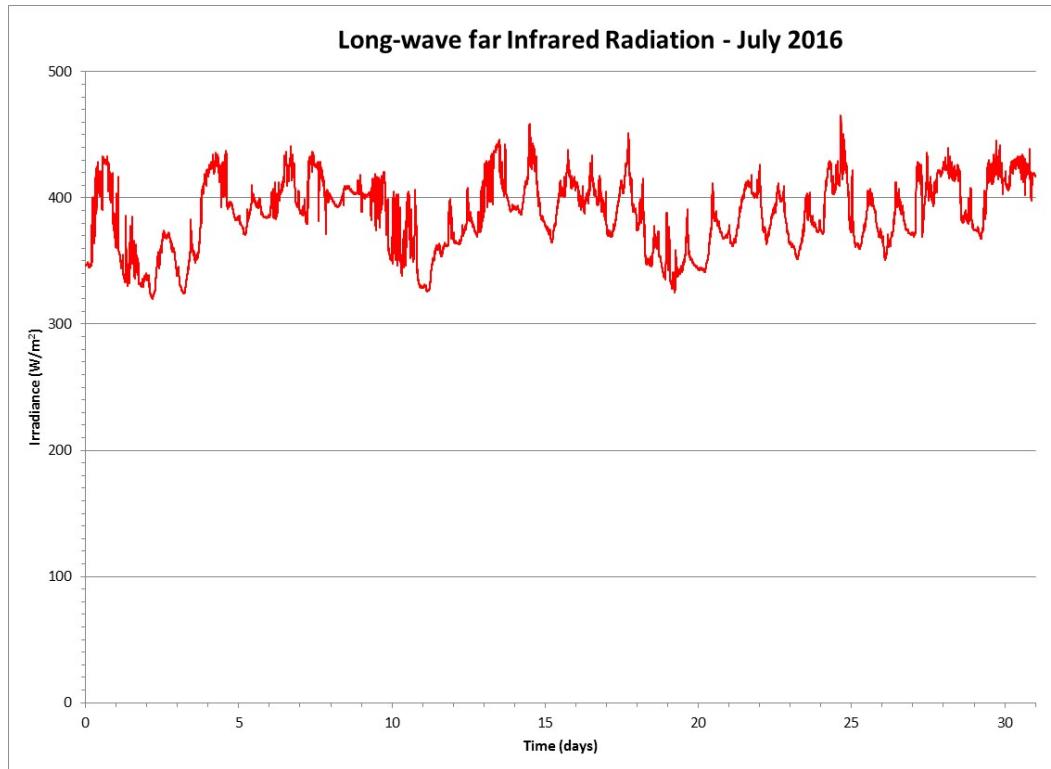


Figure 167 Long-wave Far Infrared Radiation for the Month of July 2016

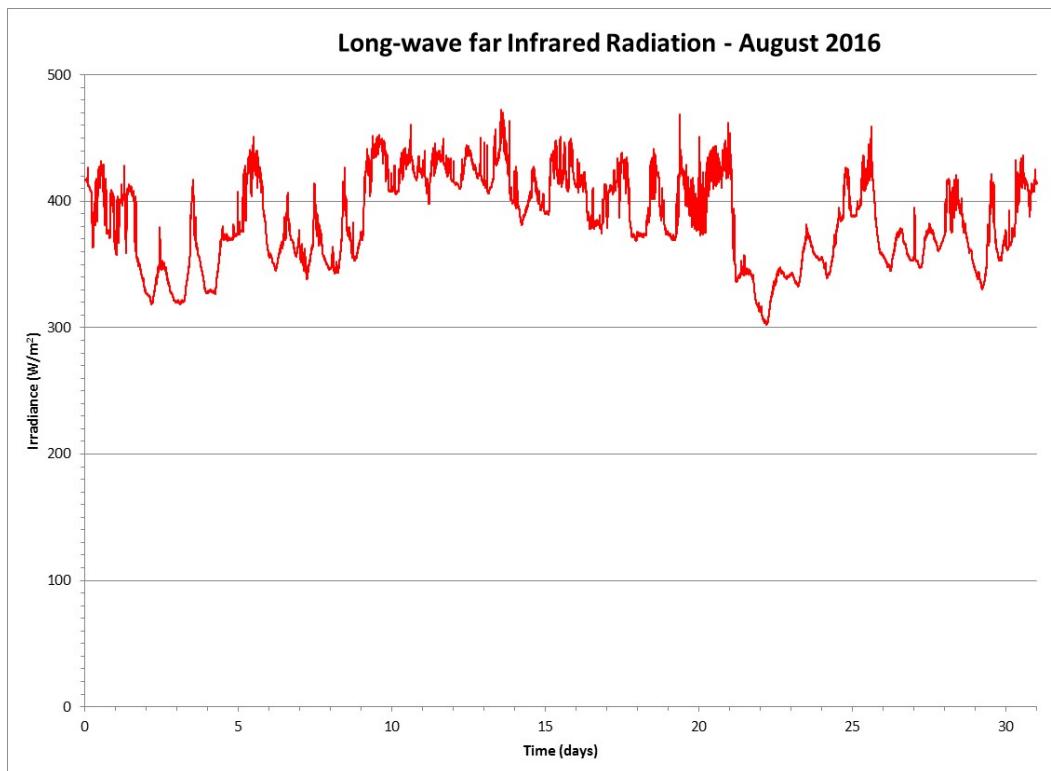


Figure 168 Long-wave Far Infrared Radiation for the Month of August 2016

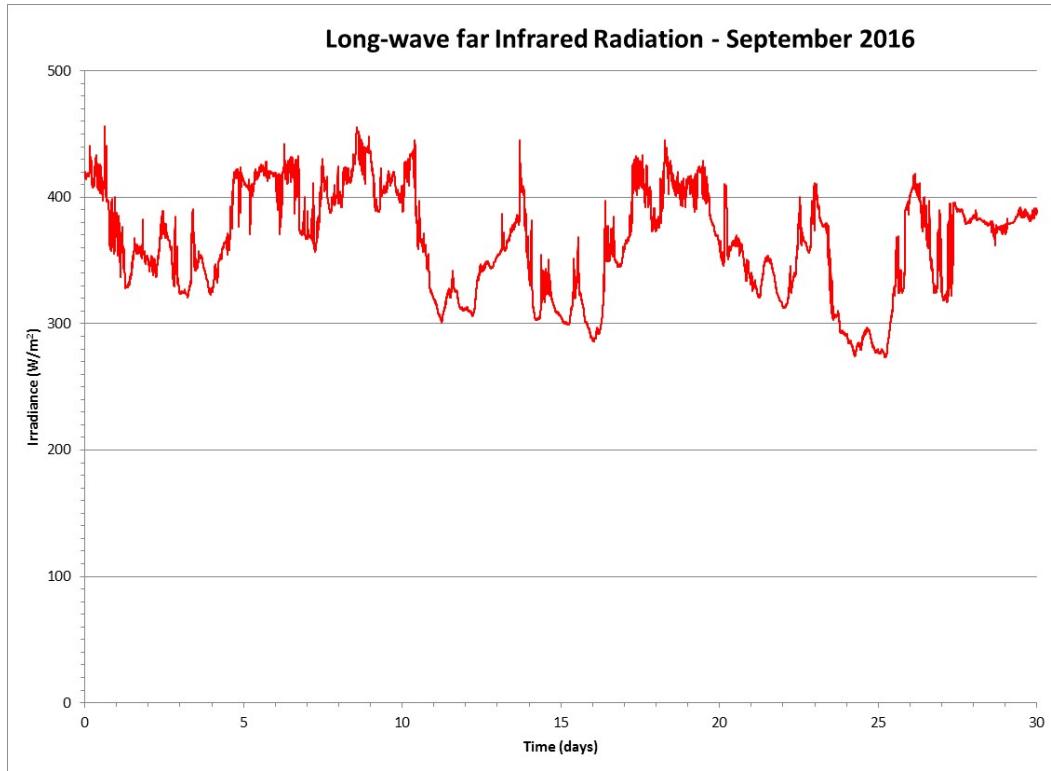


Figure 169 Long-wave Far Infrared Radiation for the Month of September 2016

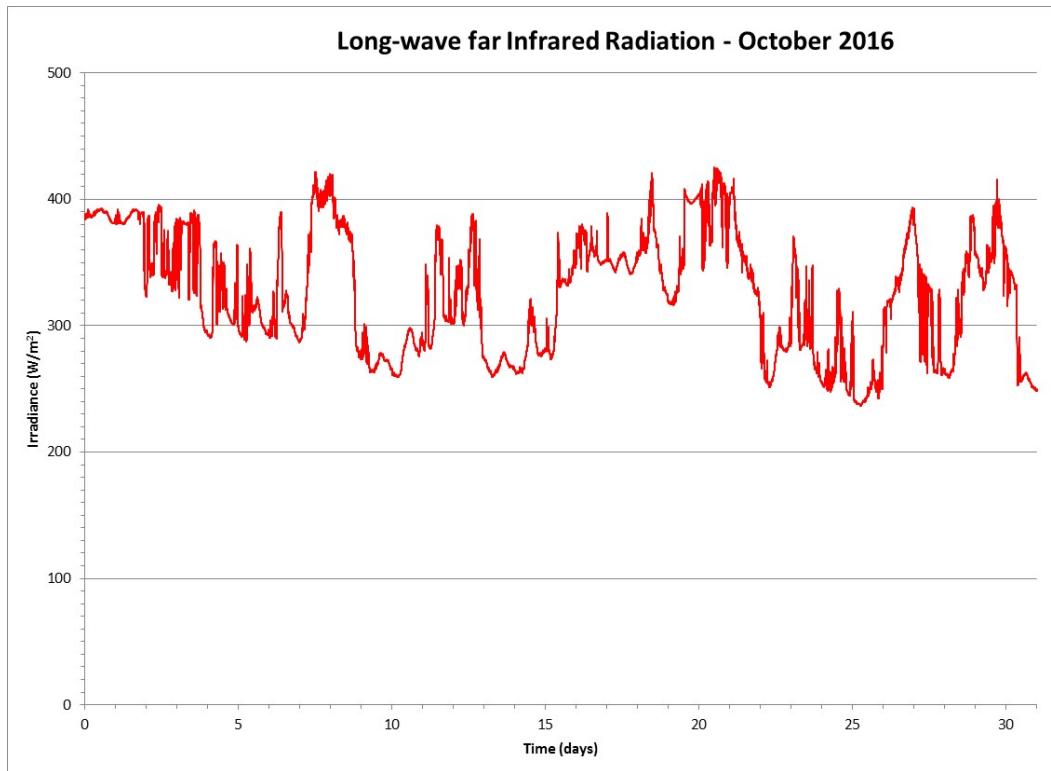


Figure 170 Long-wave Far Infrared Radiation for the Month of October 2016

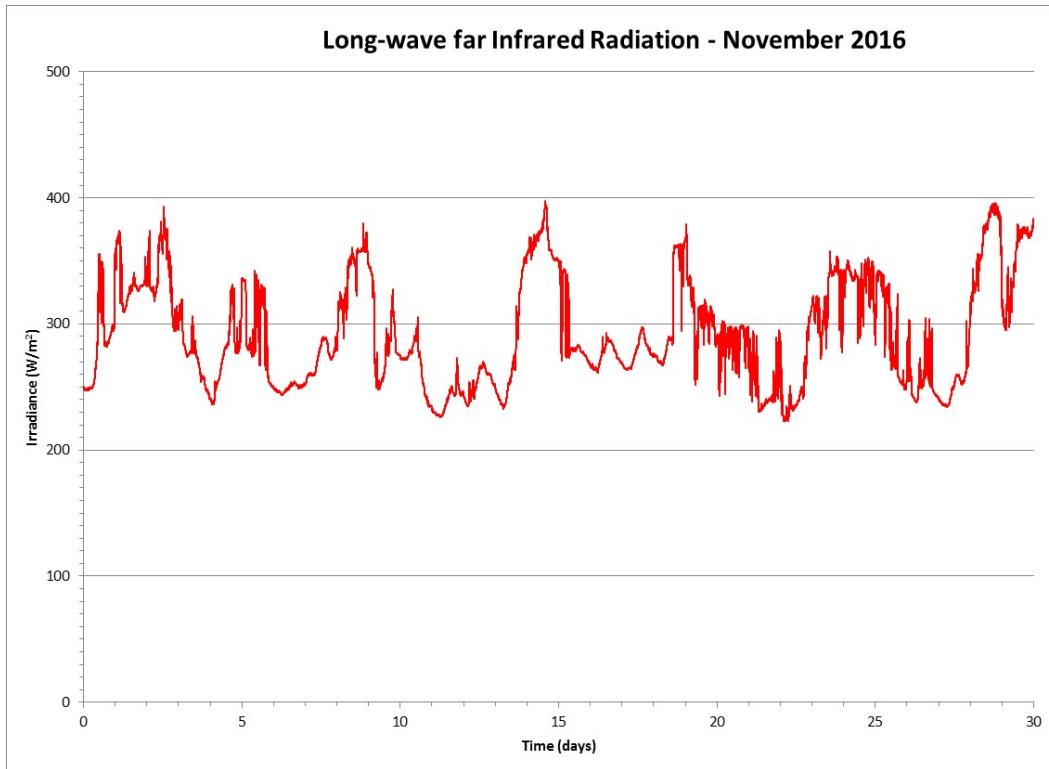


Figure 171 Long-wave Far Infrared Radiation for the Month of November 2016

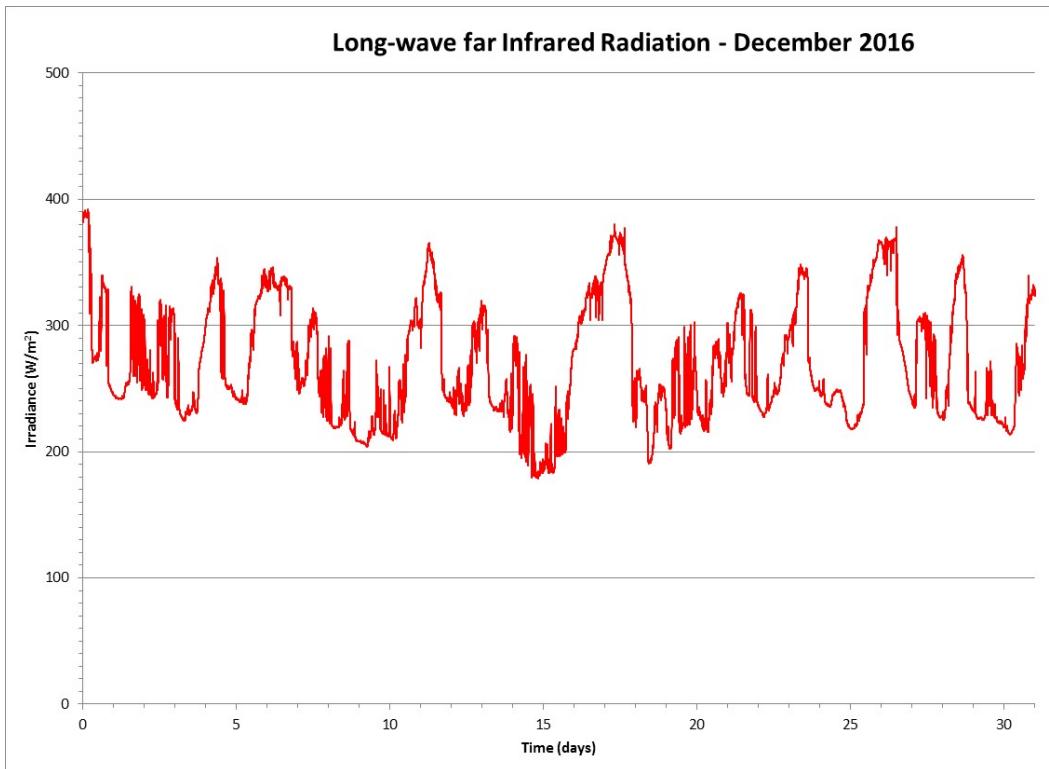


Figure 172 Long-wave Far Infrared Radiation for the Month of December 2016

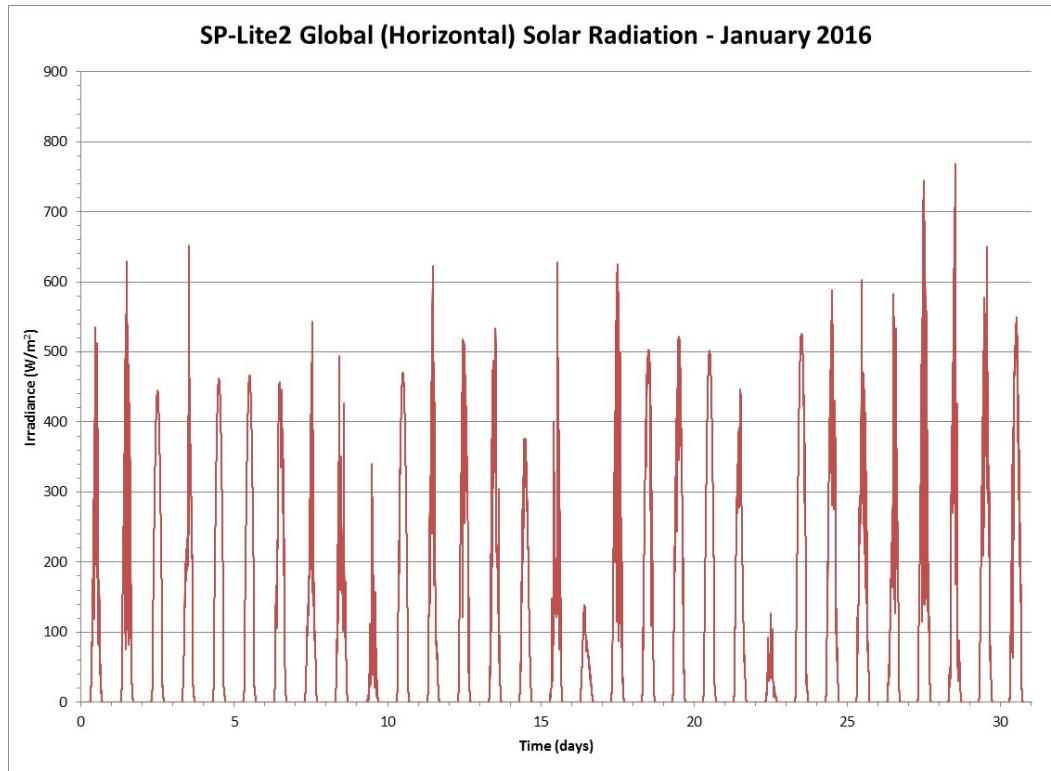


Figure 173 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of January 2016

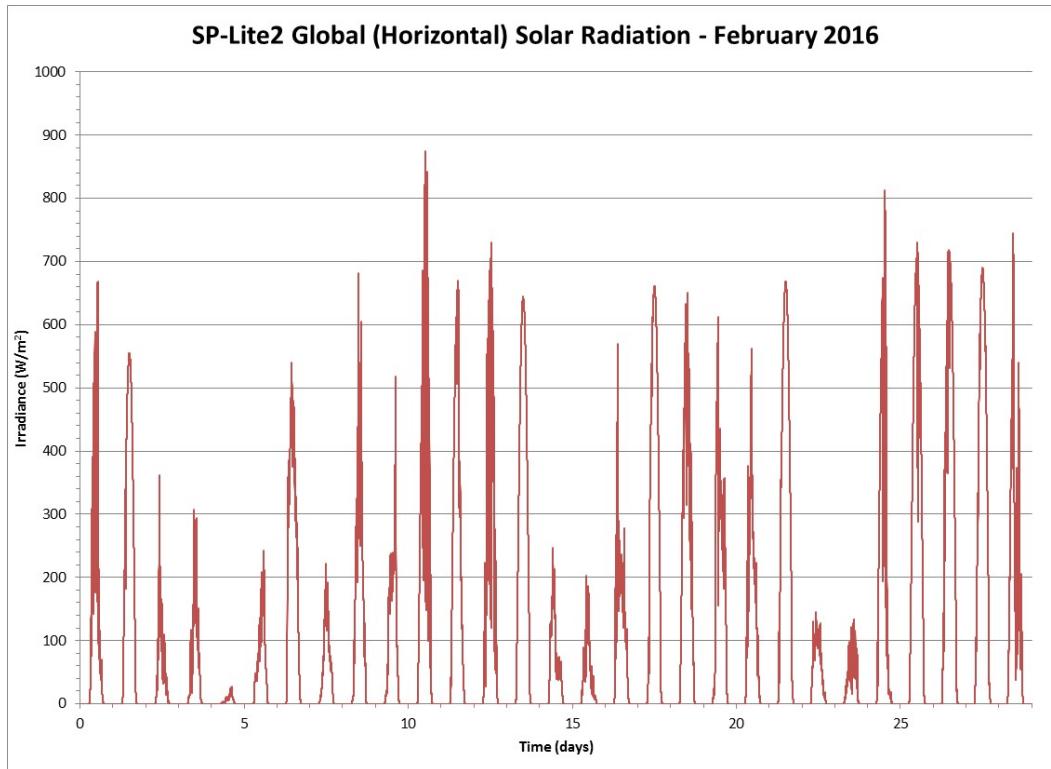


Figure 174 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of February 2016

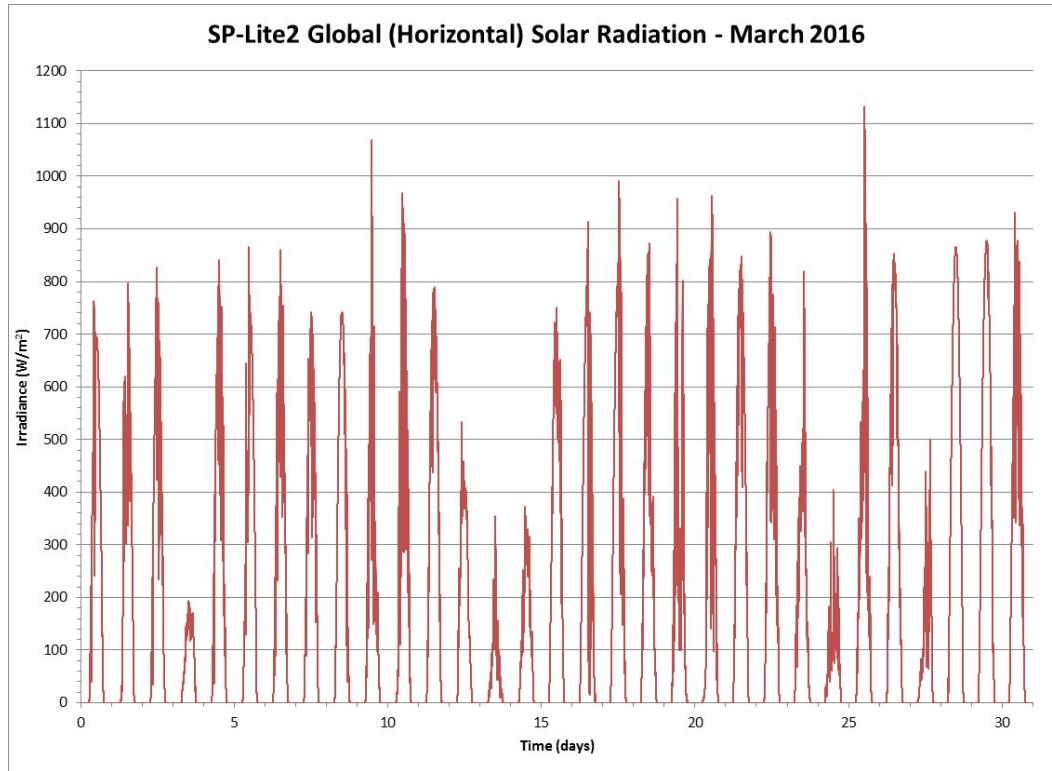


Figure 175 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of March 2016

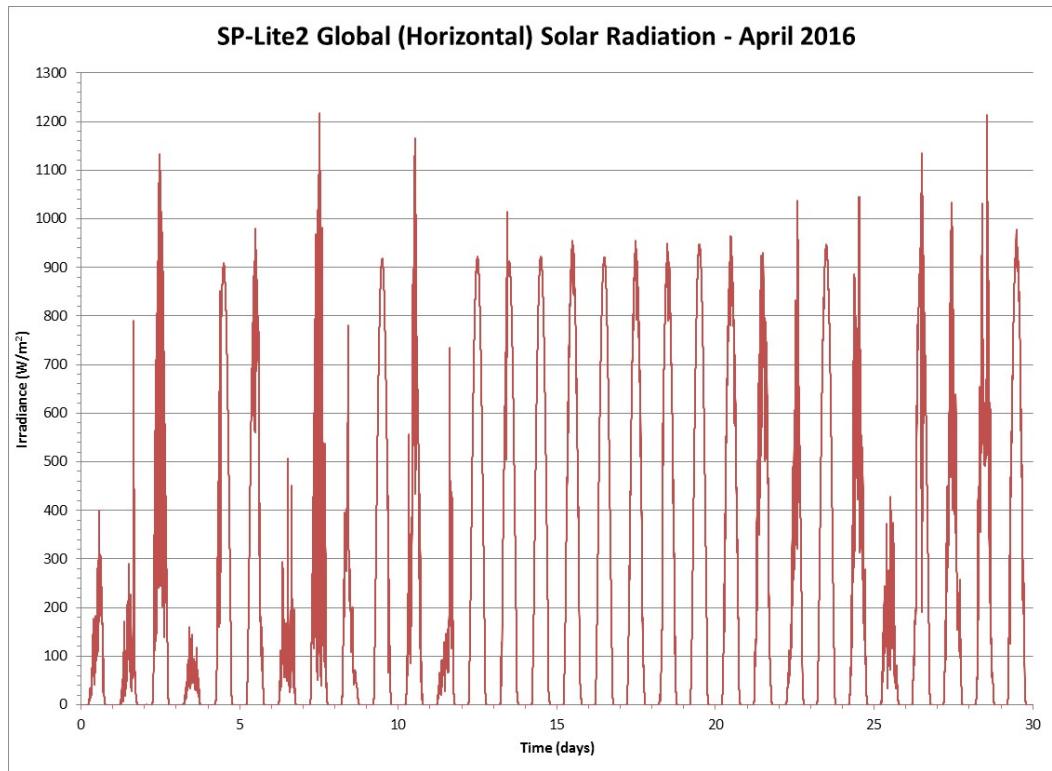


Figure 176 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of April 2016

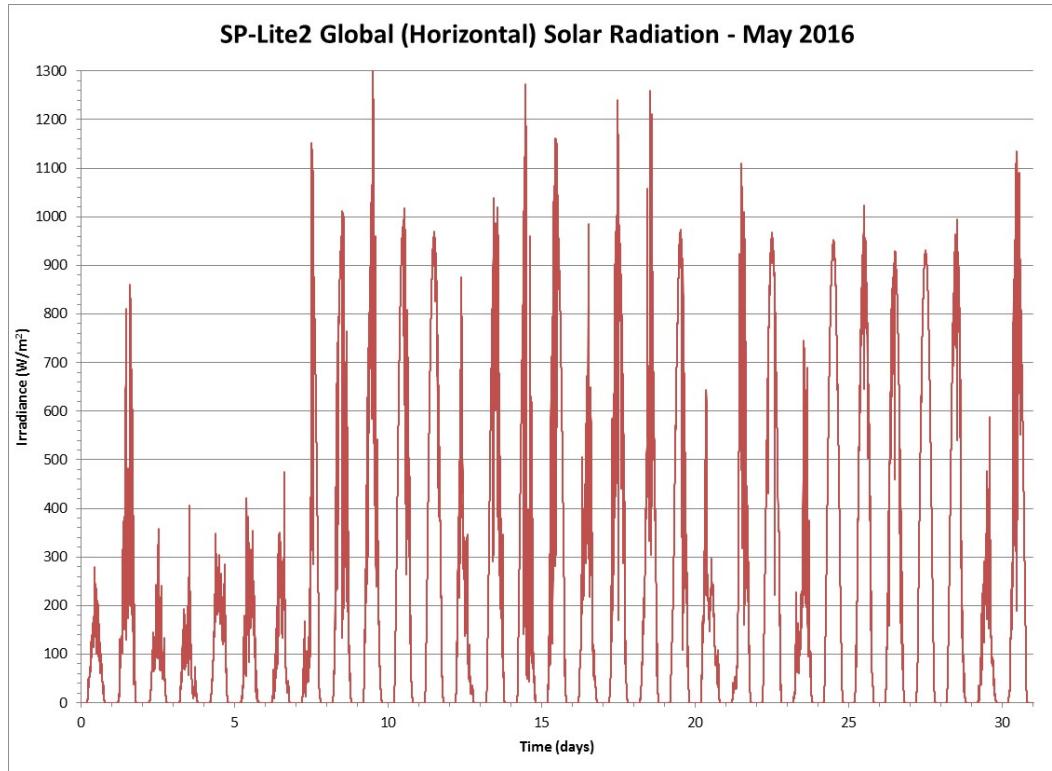


Figure 177 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of May 2016

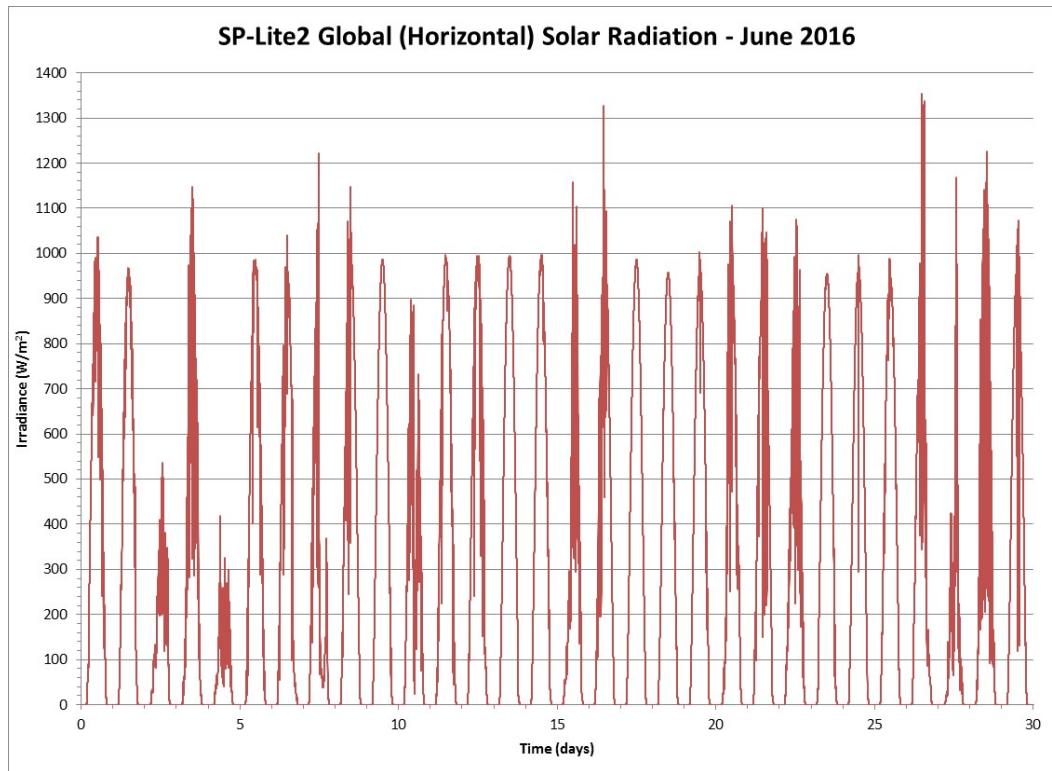


Figure 178 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of June 2016

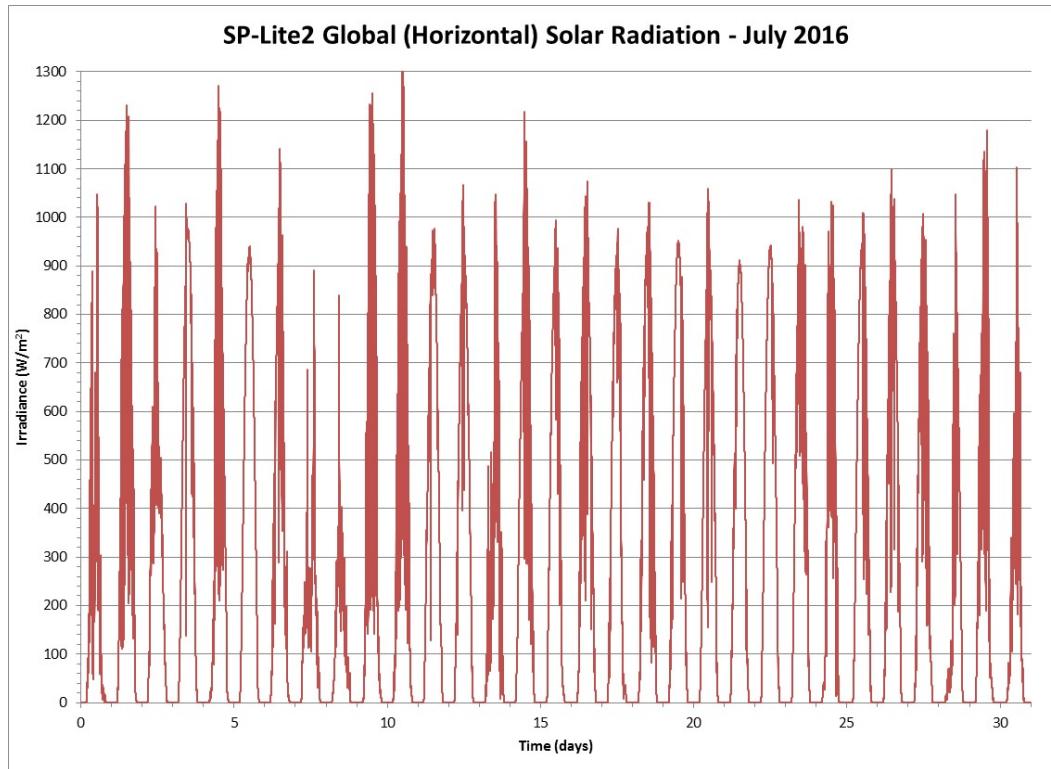


Figure 179 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of July 2016

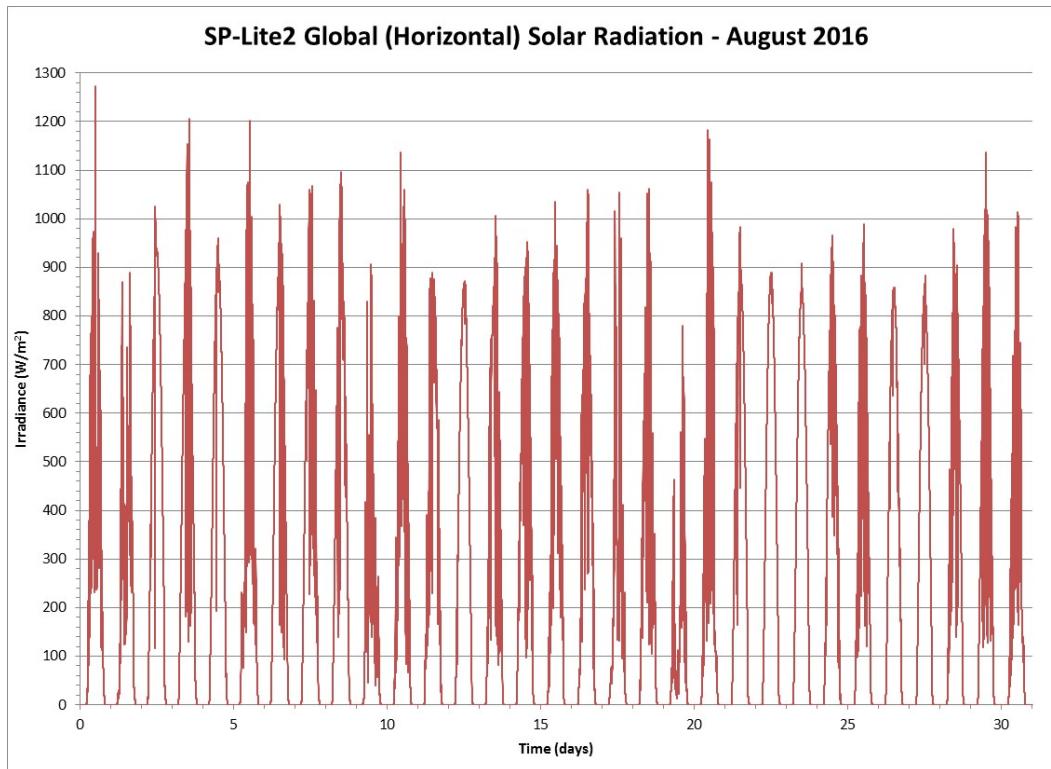


Figure 180 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of August 2016

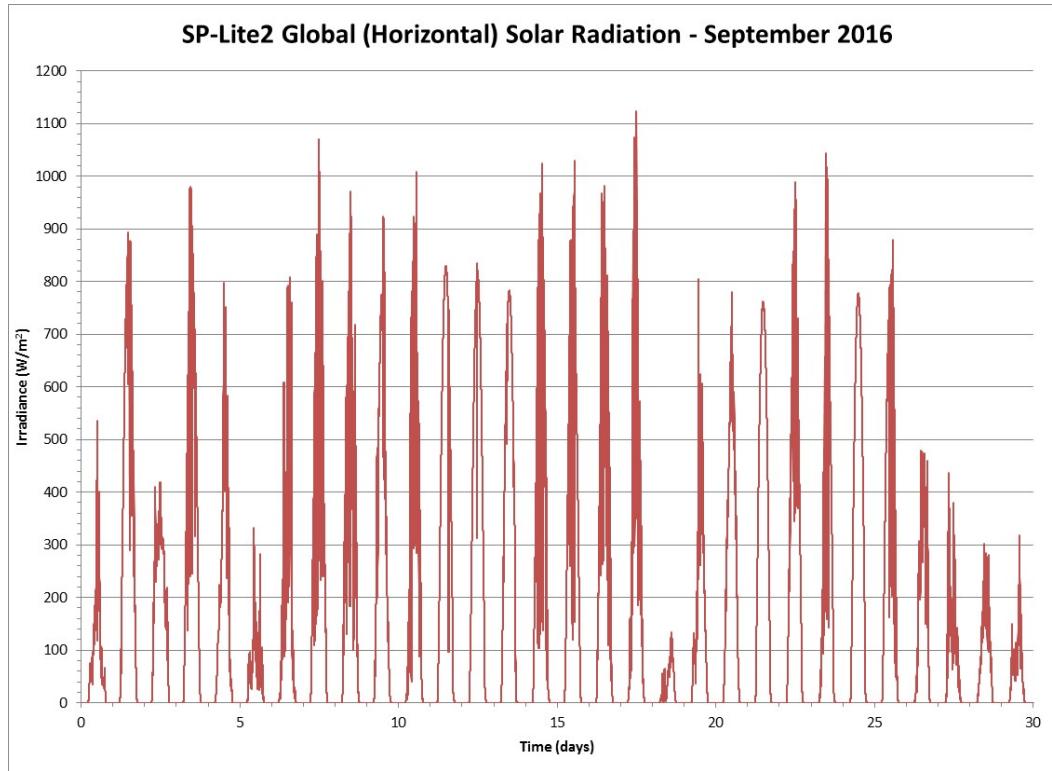


Figure 181 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of September 2016

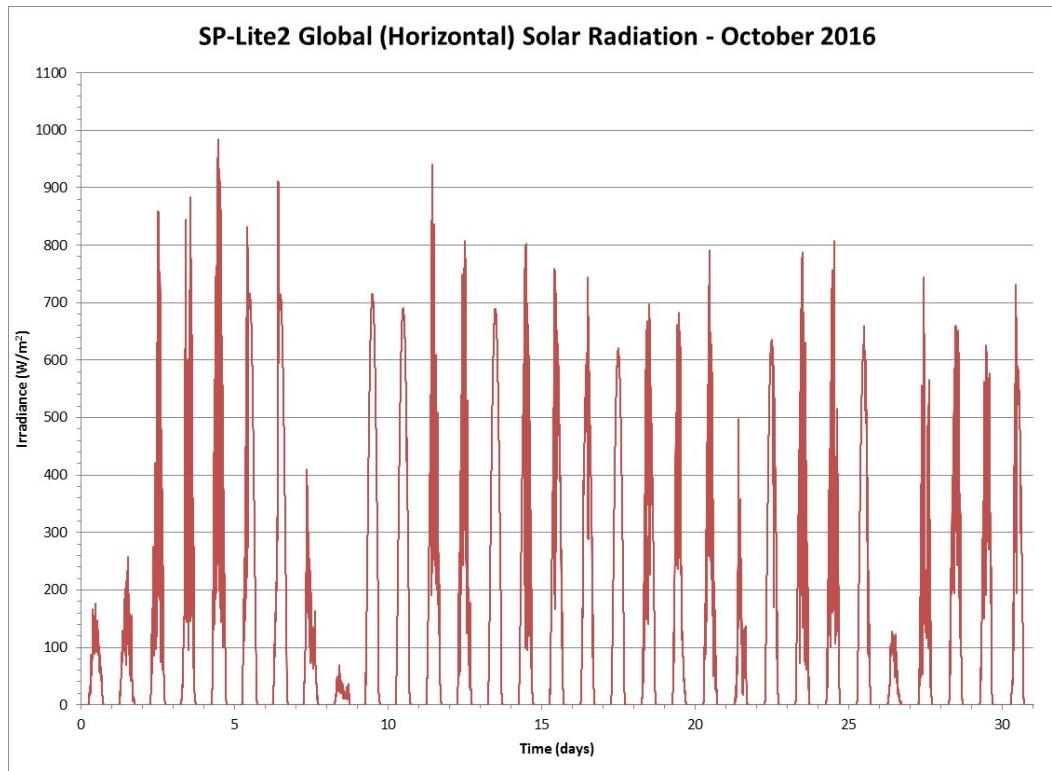


Figure 182 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of October 2016

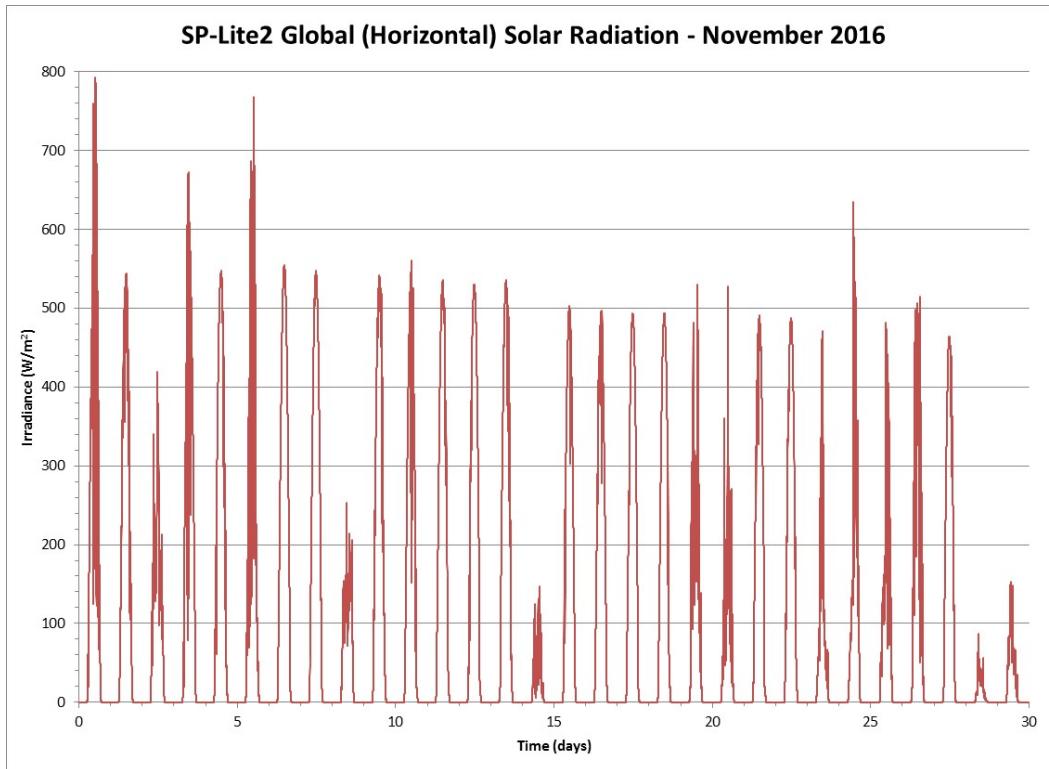


Figure 183 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of November 2016

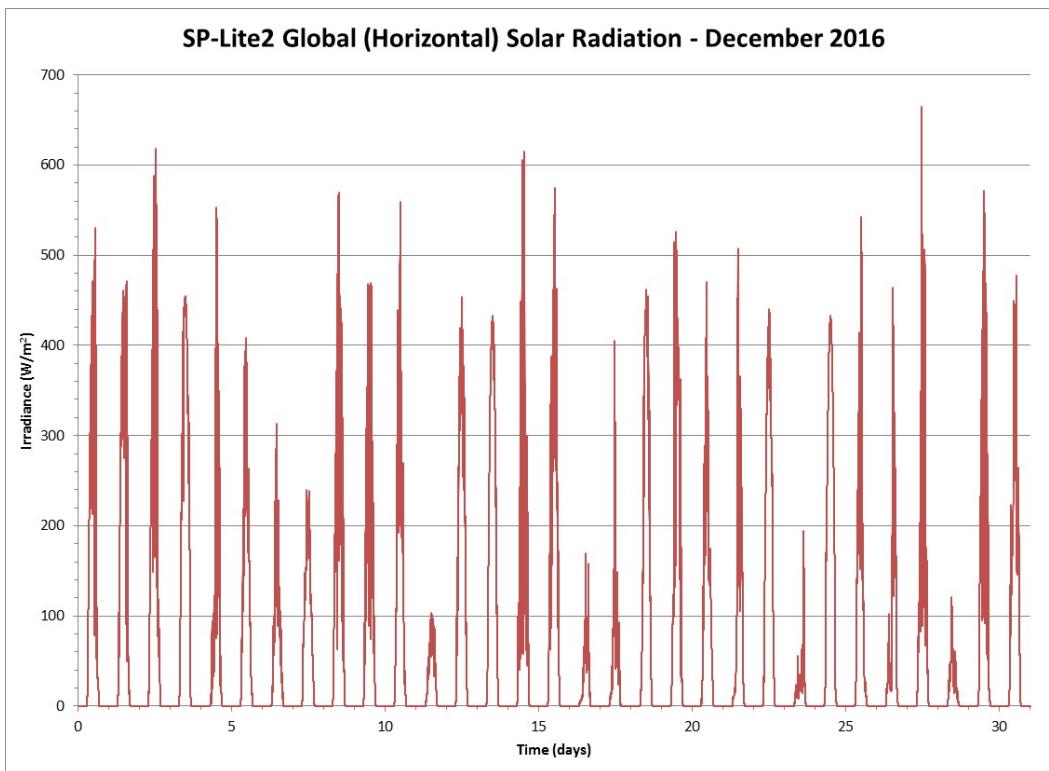


Figure 184 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of December 2016

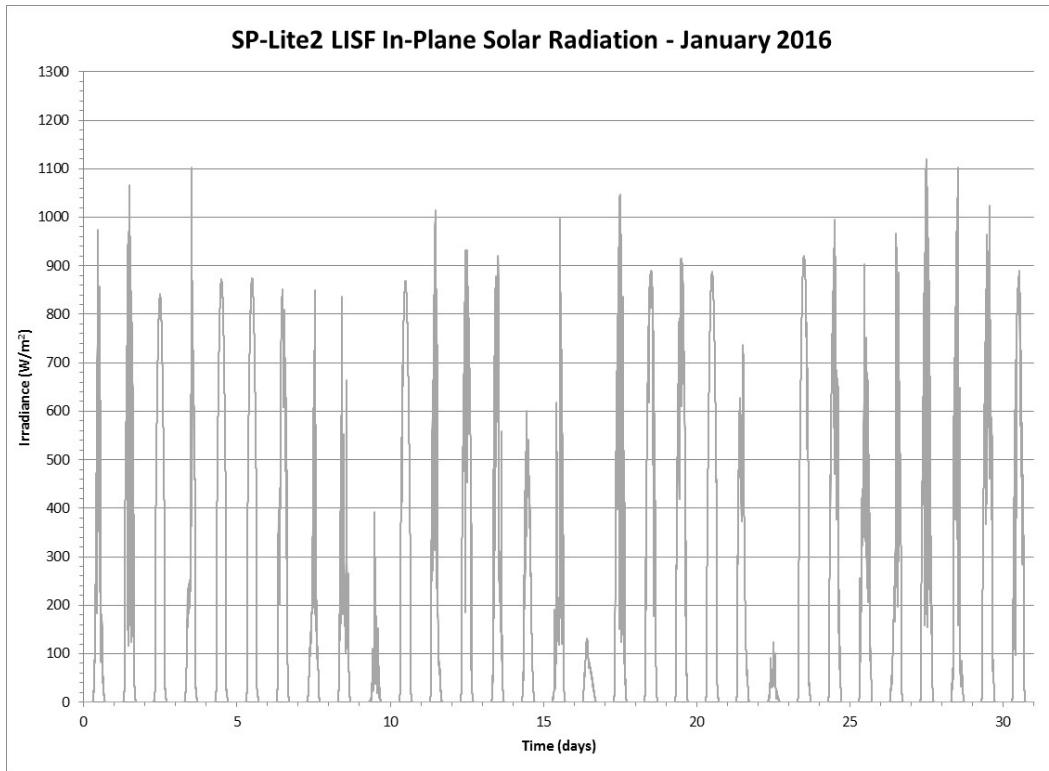


Figure 185 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for January 2016

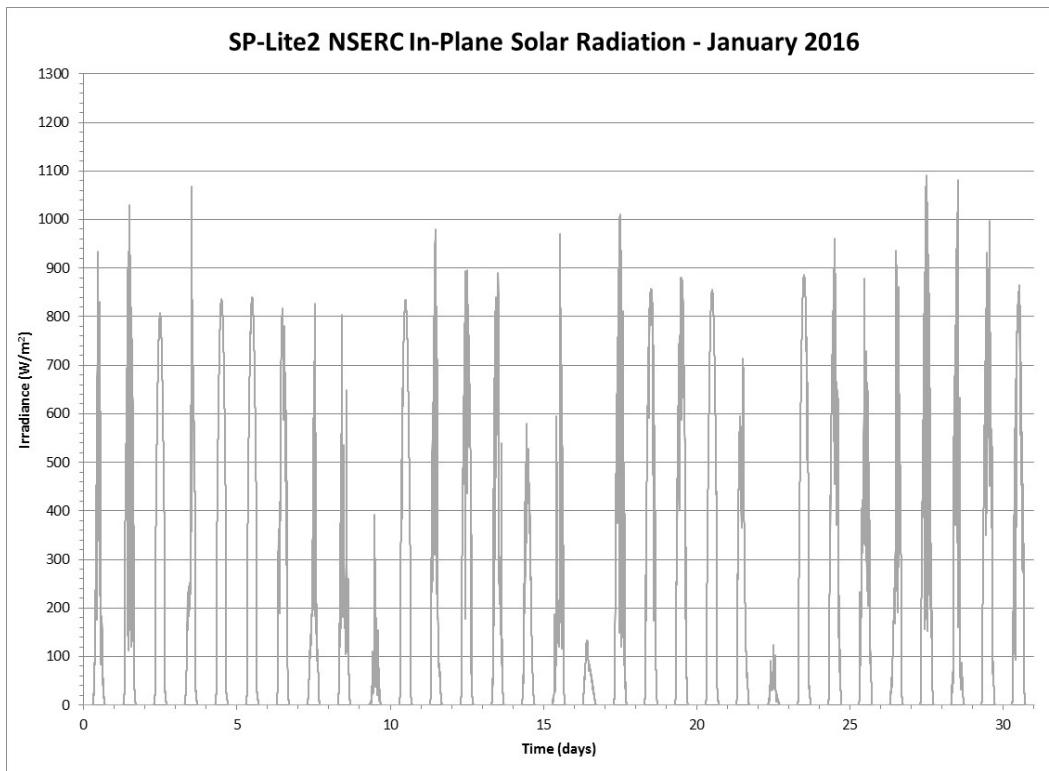


Figure 186 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for January 2016

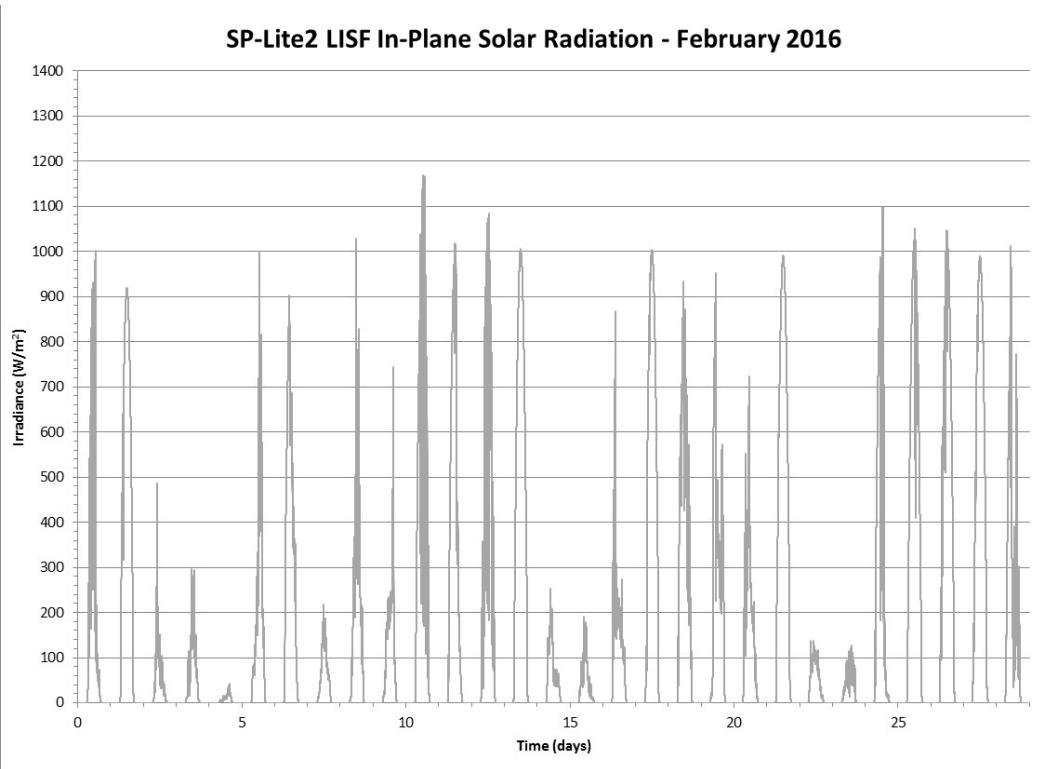


Figure 187 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for February 2016

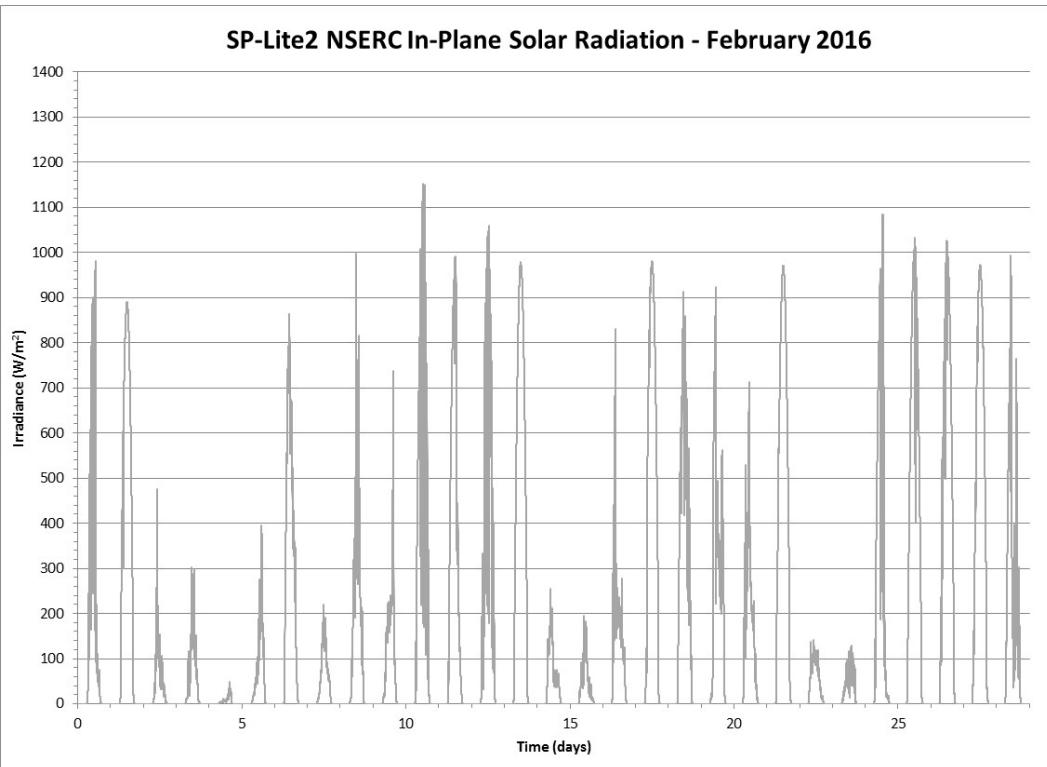


Figure 188 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for February 2016

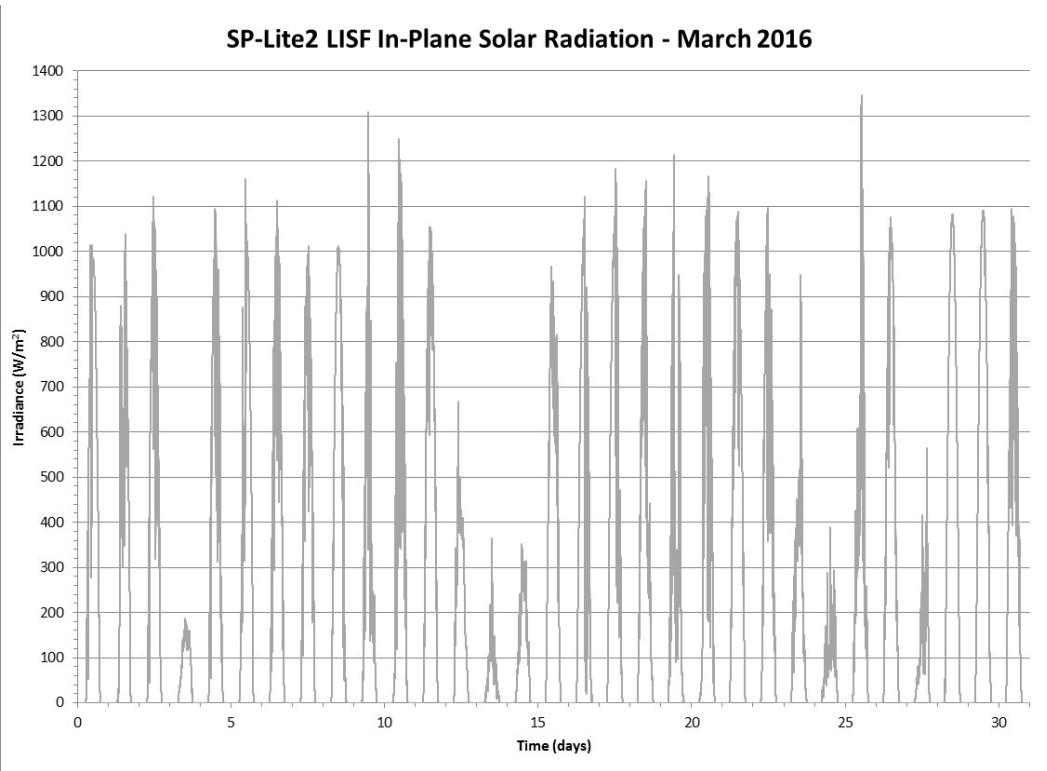


Figure 189 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for March 2016

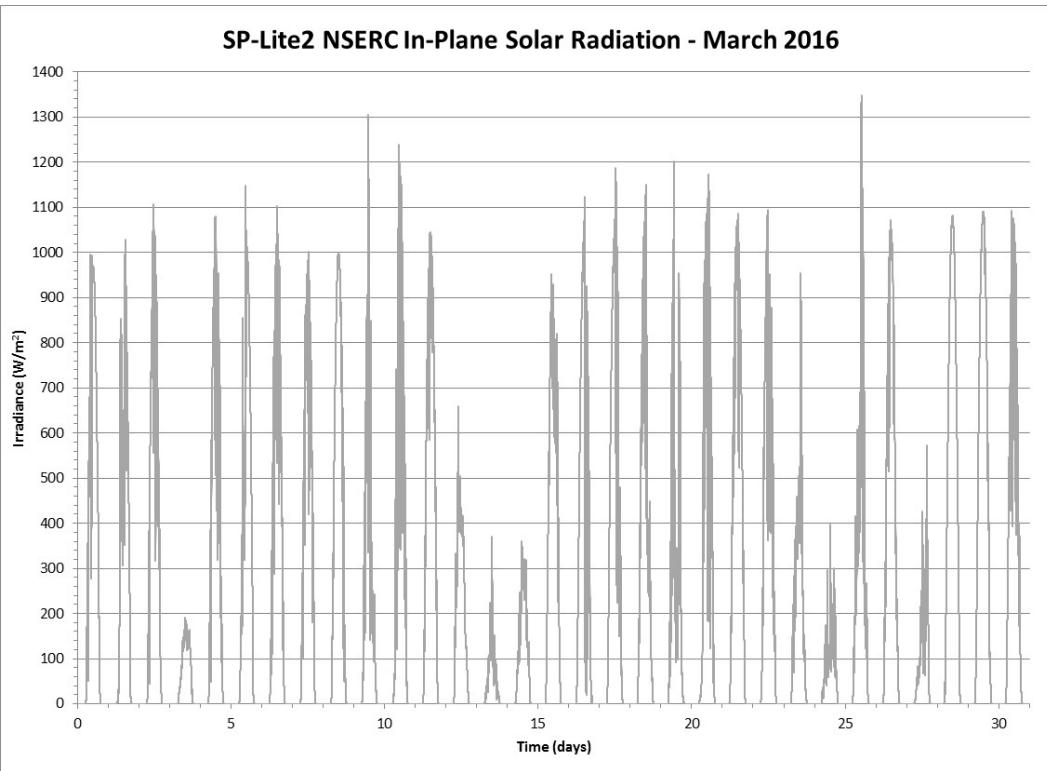


Figure 190 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for March 2016

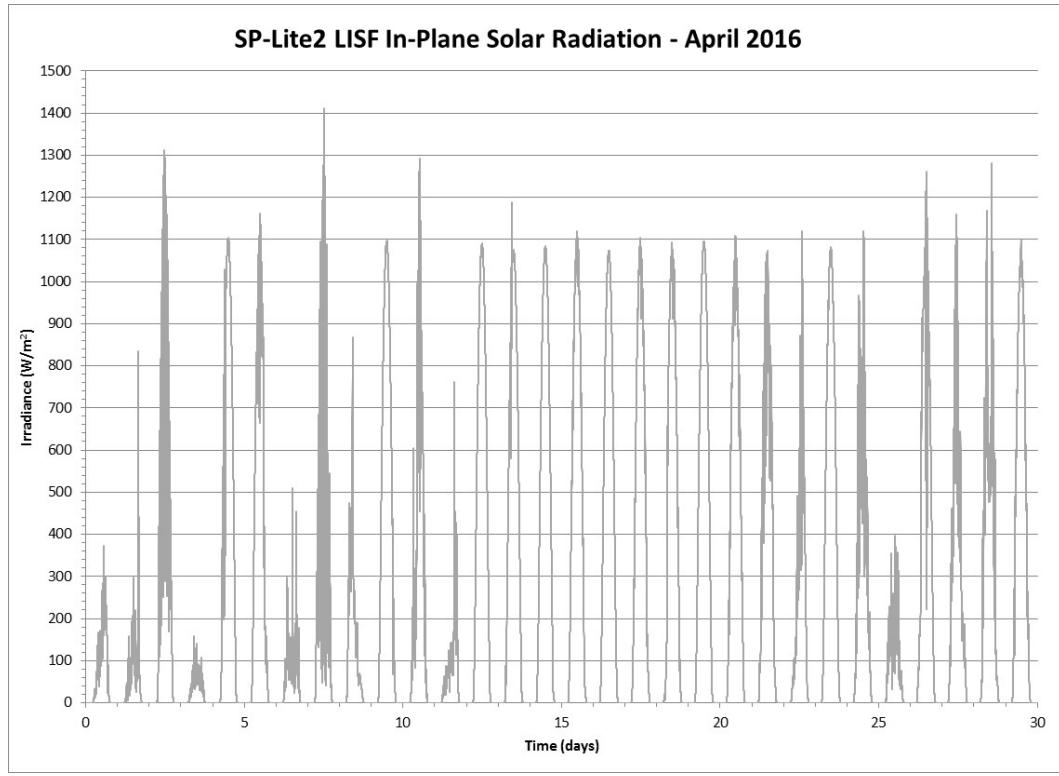


Figure 191 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for April 2016

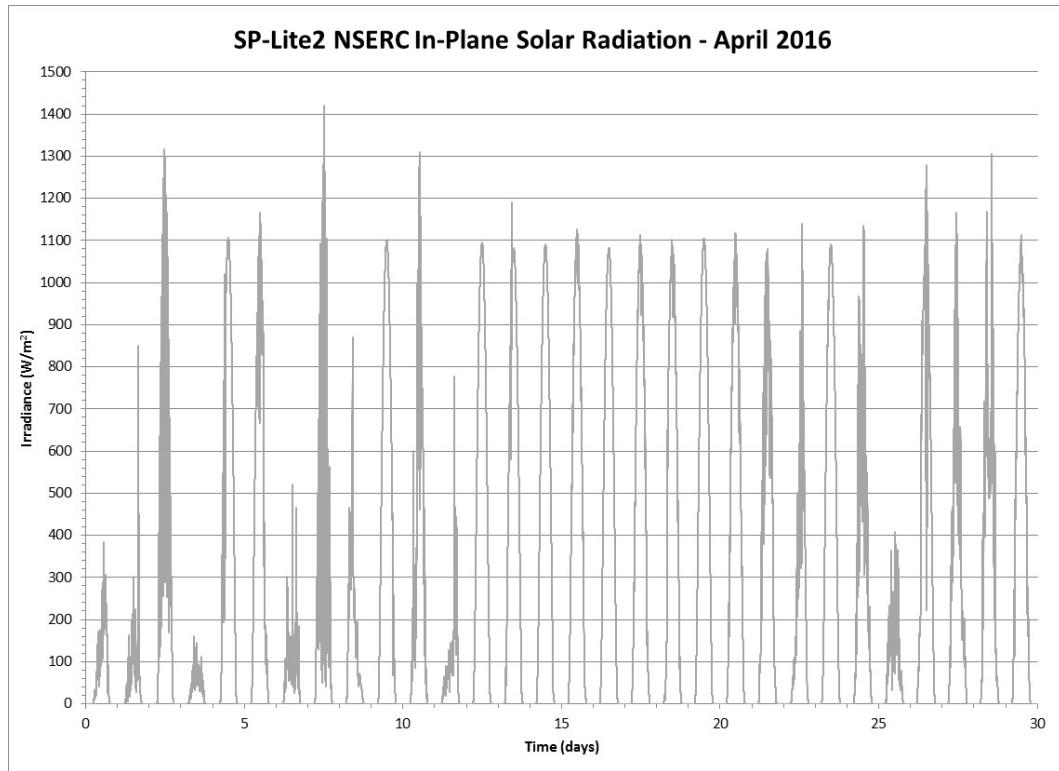


Figure 192 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for April 2016

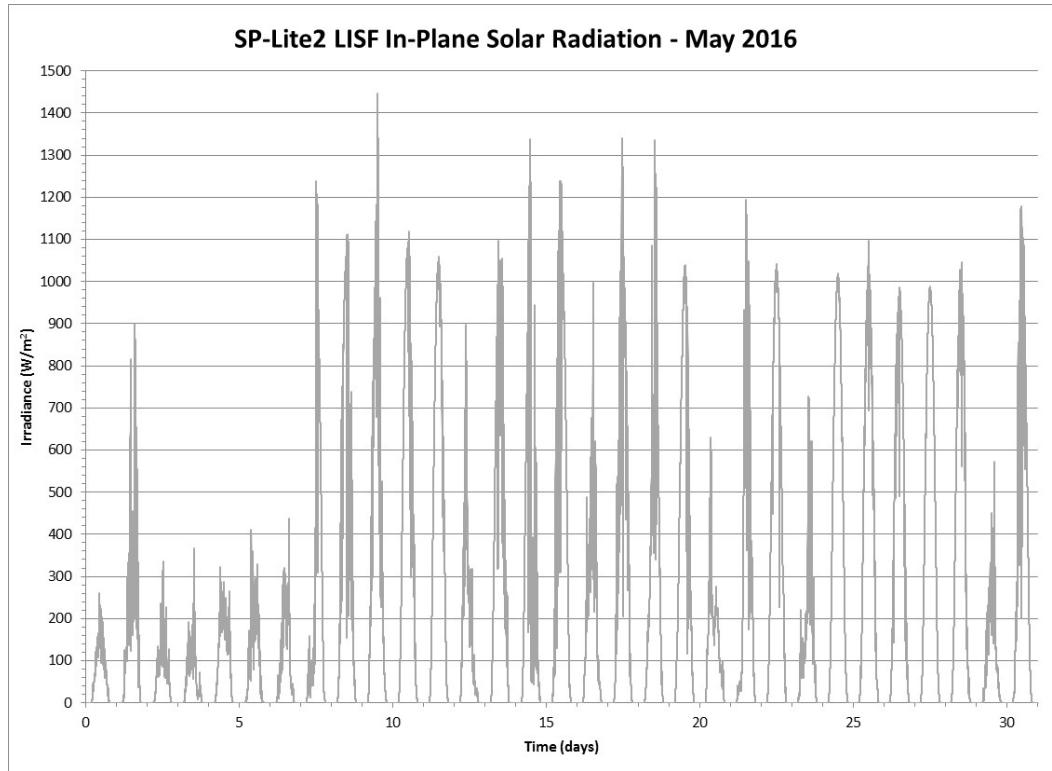


Figure 193 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for May 2016

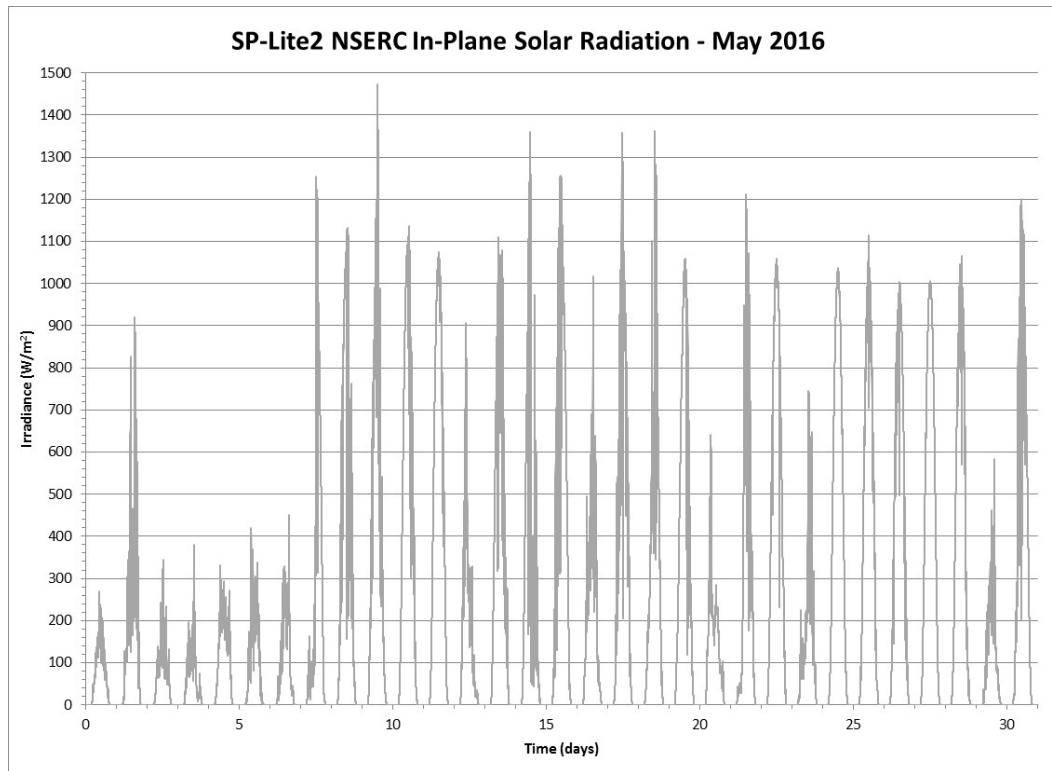


Figure 194 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for May 2016

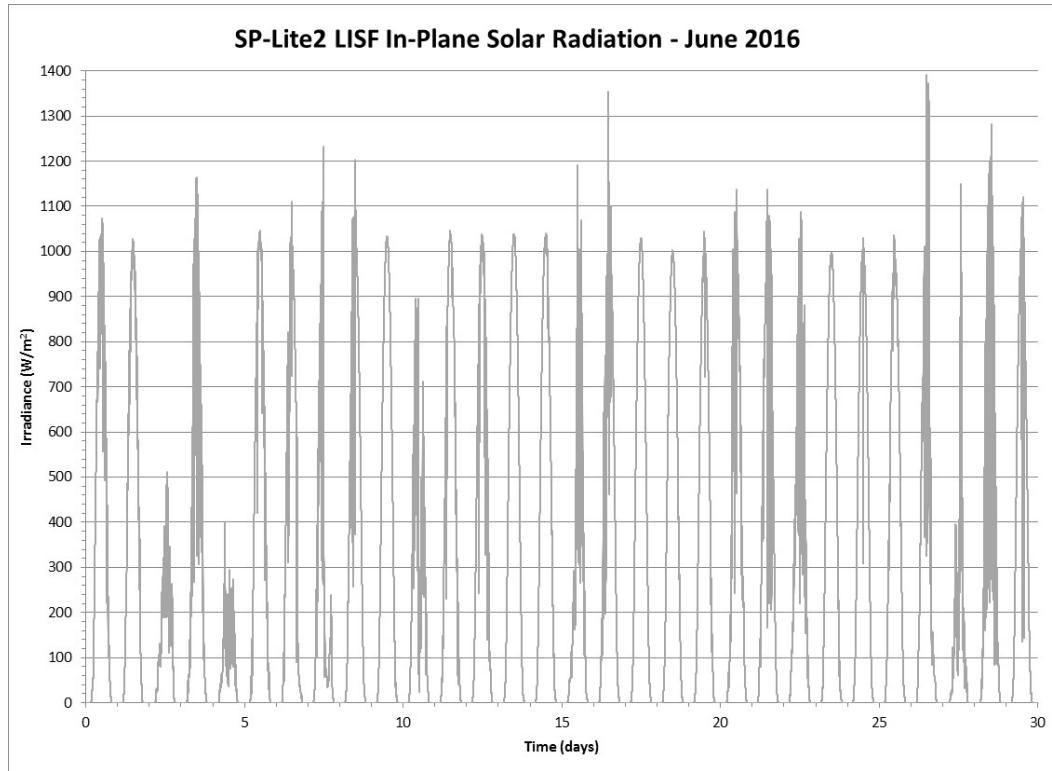


Figure 195 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for June 2016

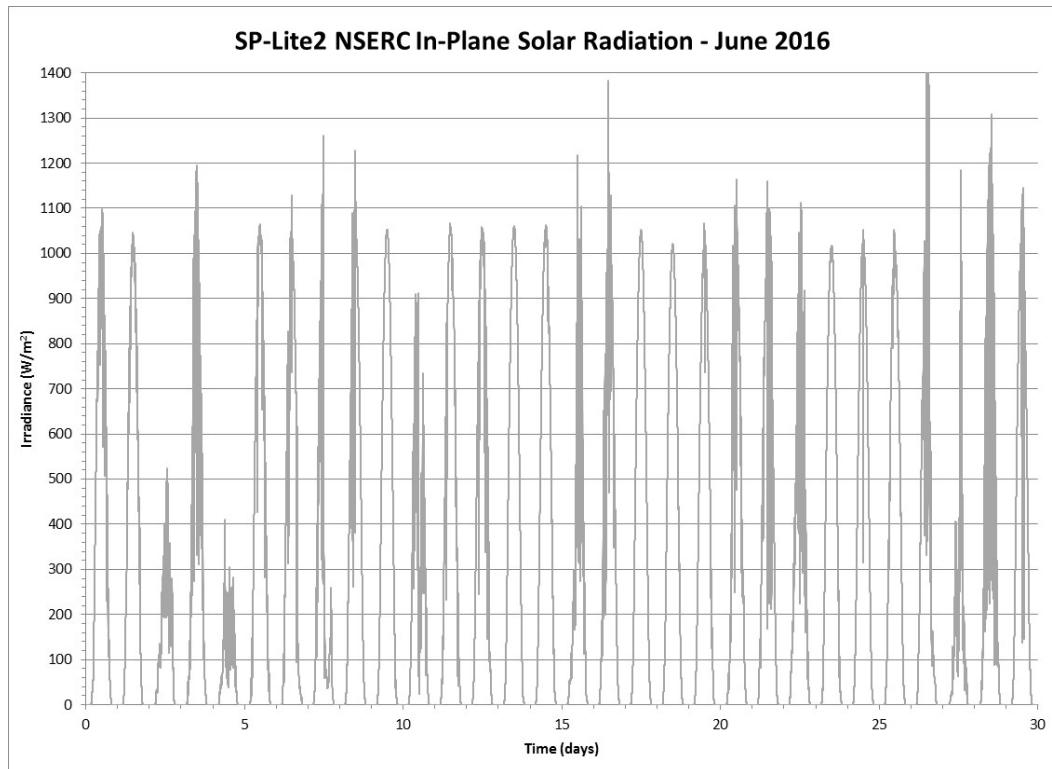


Figure 196 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for June 2016

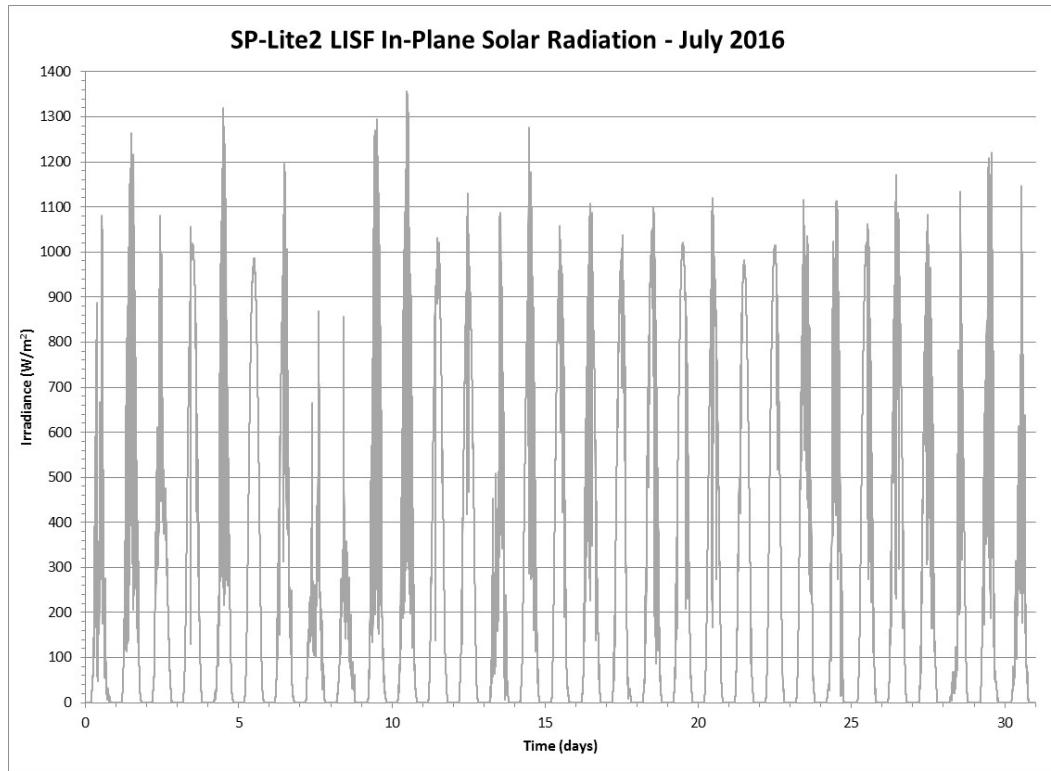


Figure 197 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for July 2016

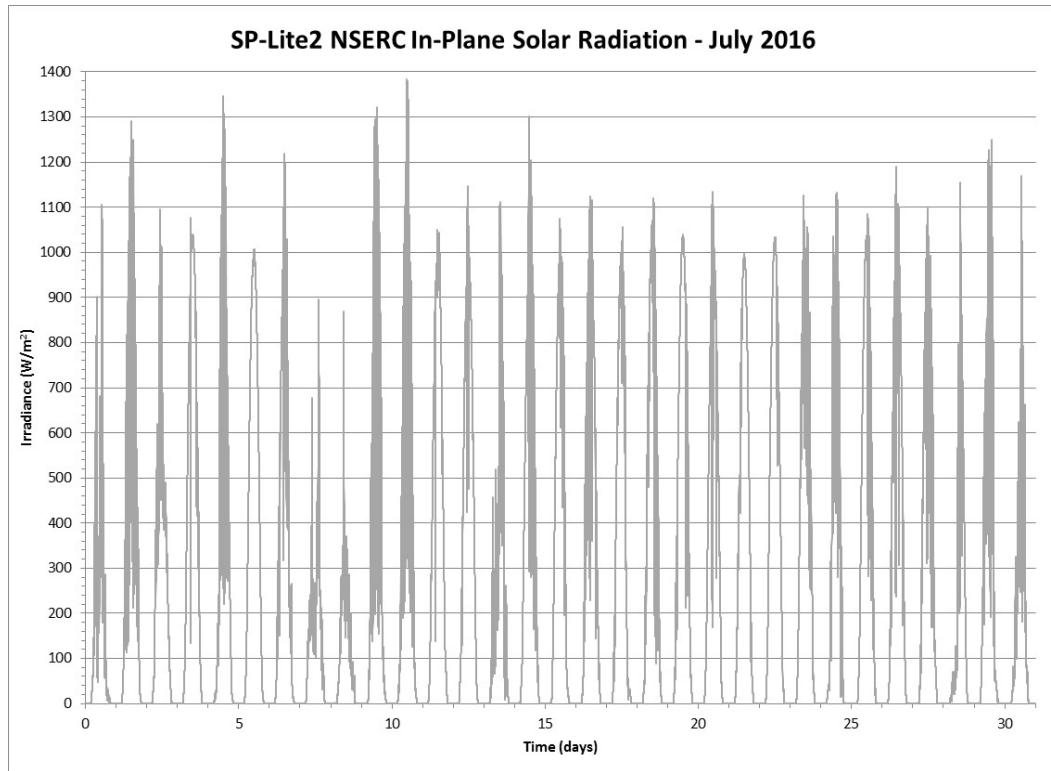


Figure 198 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for July 2016

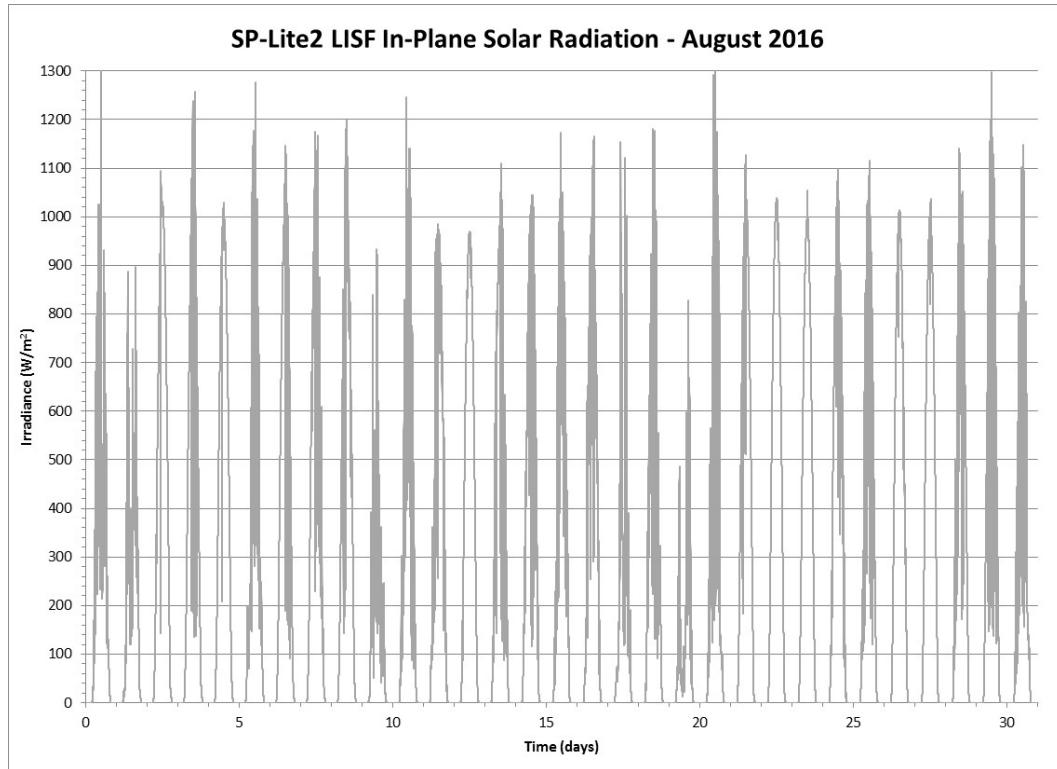


Figure 199 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for August 2016

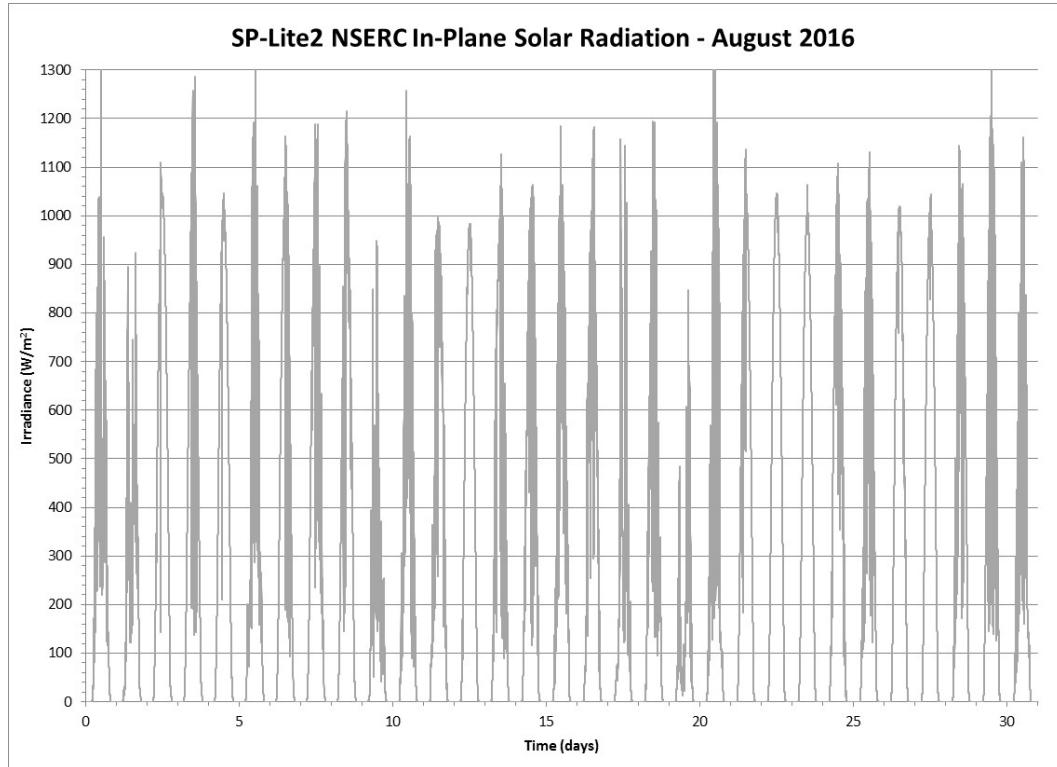


Figure 200 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for August 2016

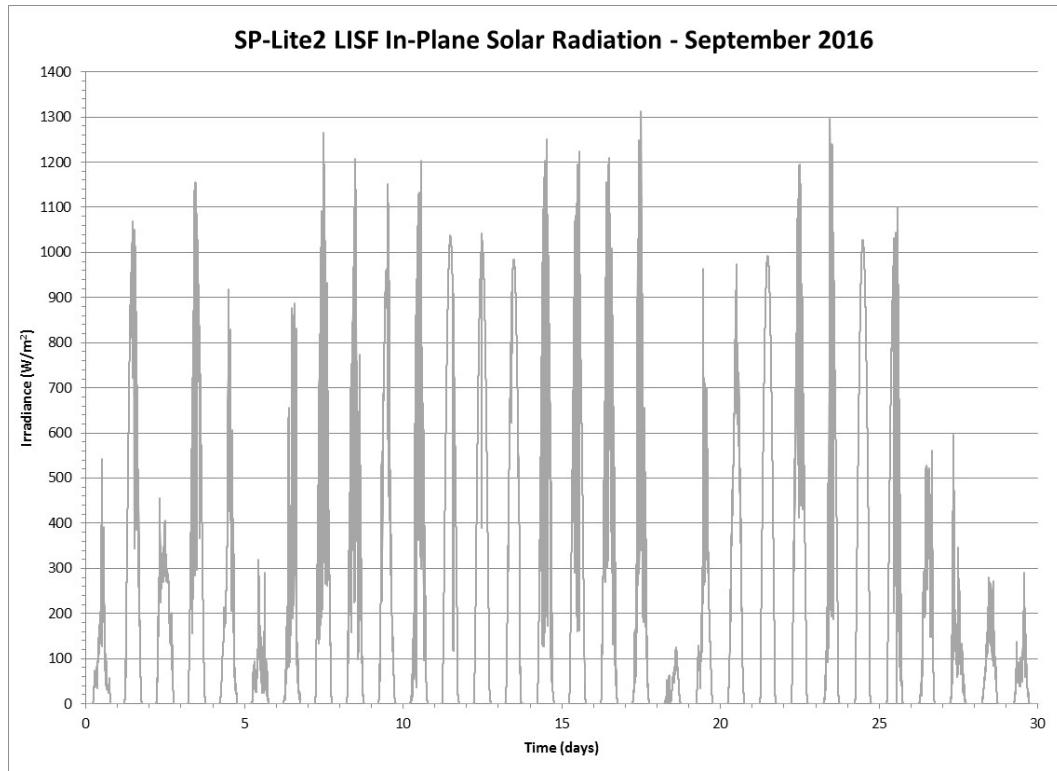


Figure 201 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for September 2016

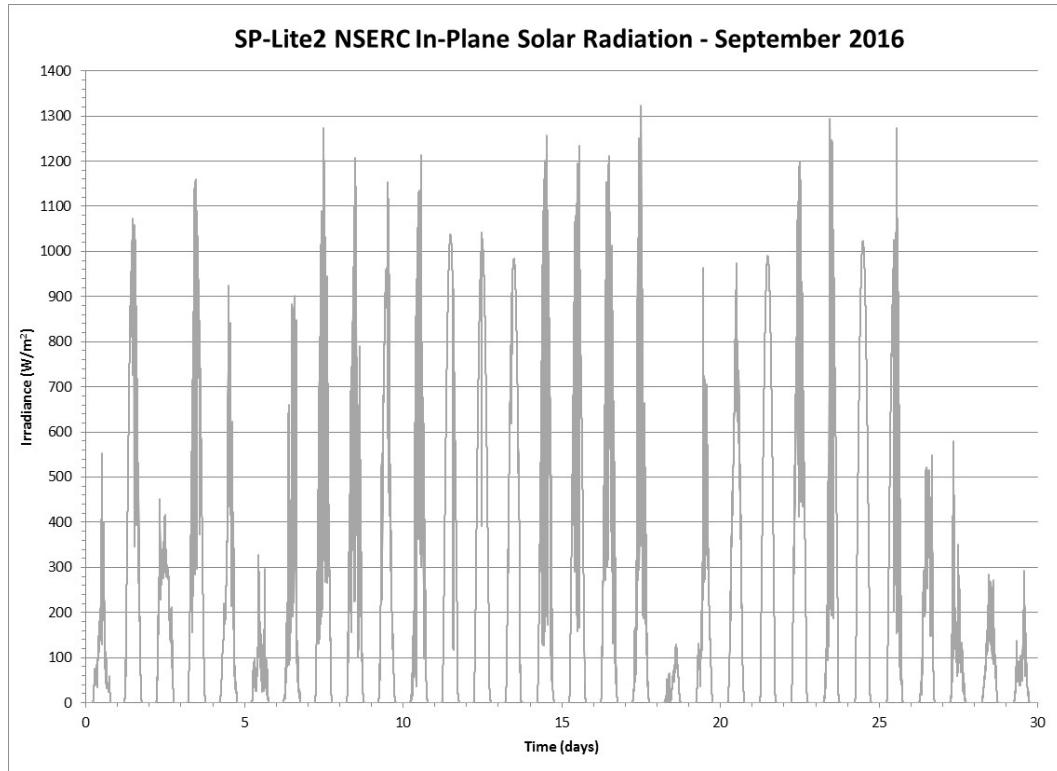


Figure 202 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for September 2016

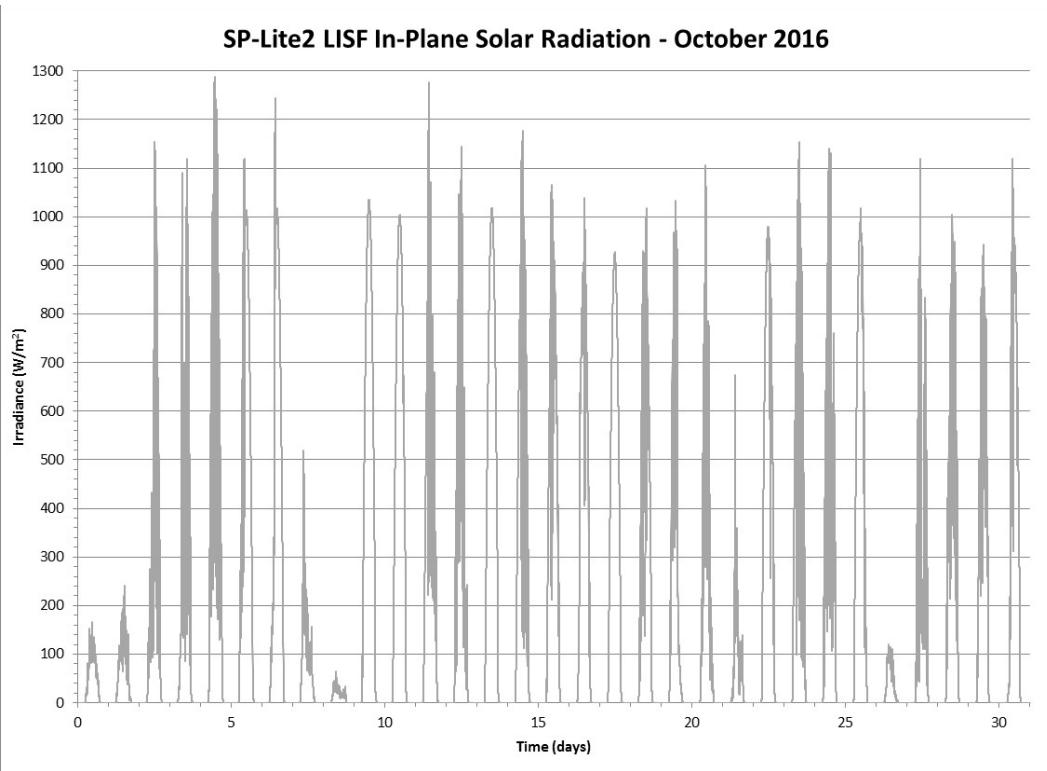


Figure 203 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for October 2016

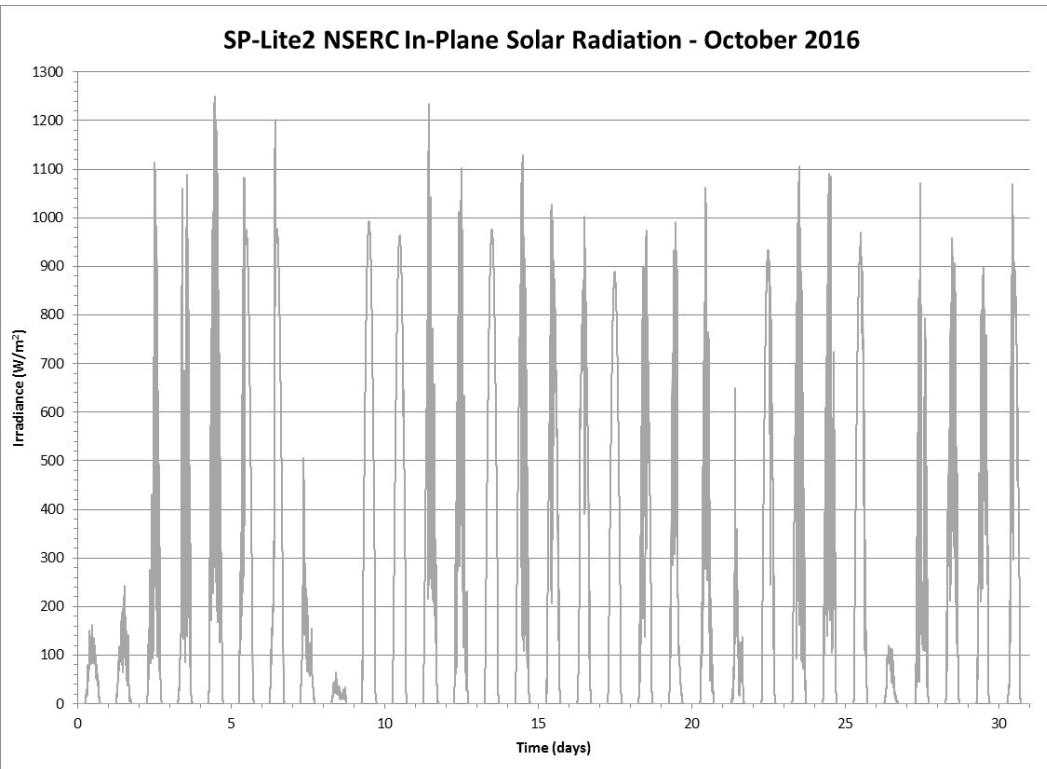


Figure 204 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for October 2016

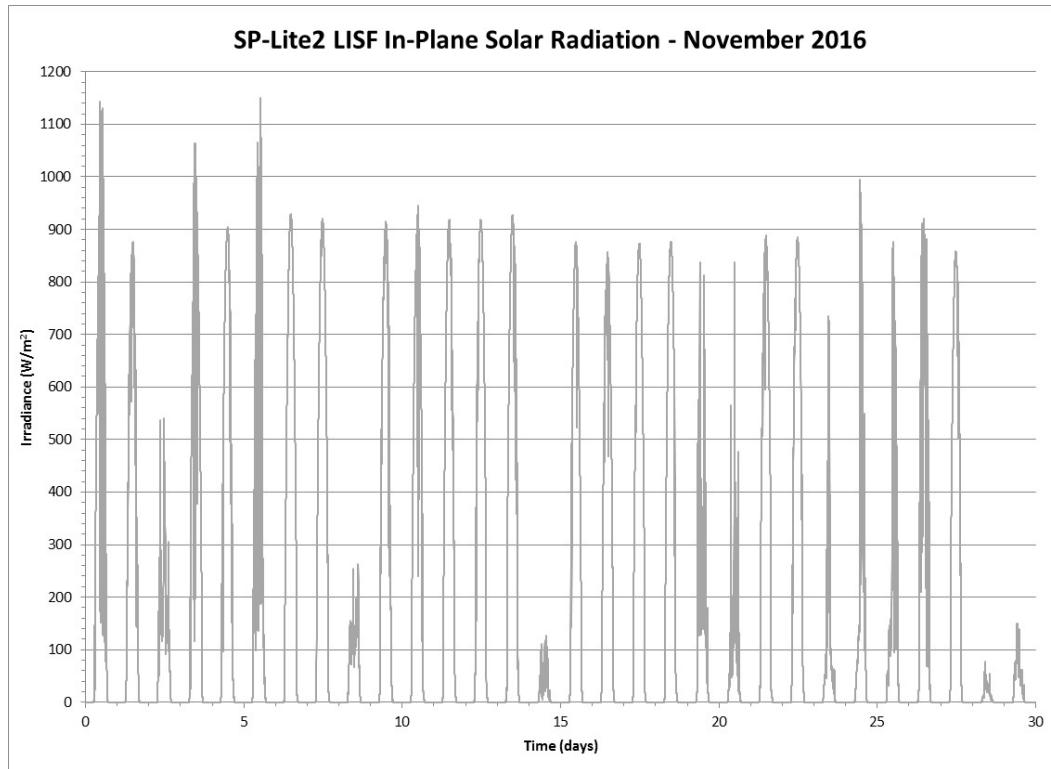


Figure 205 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for November 2016

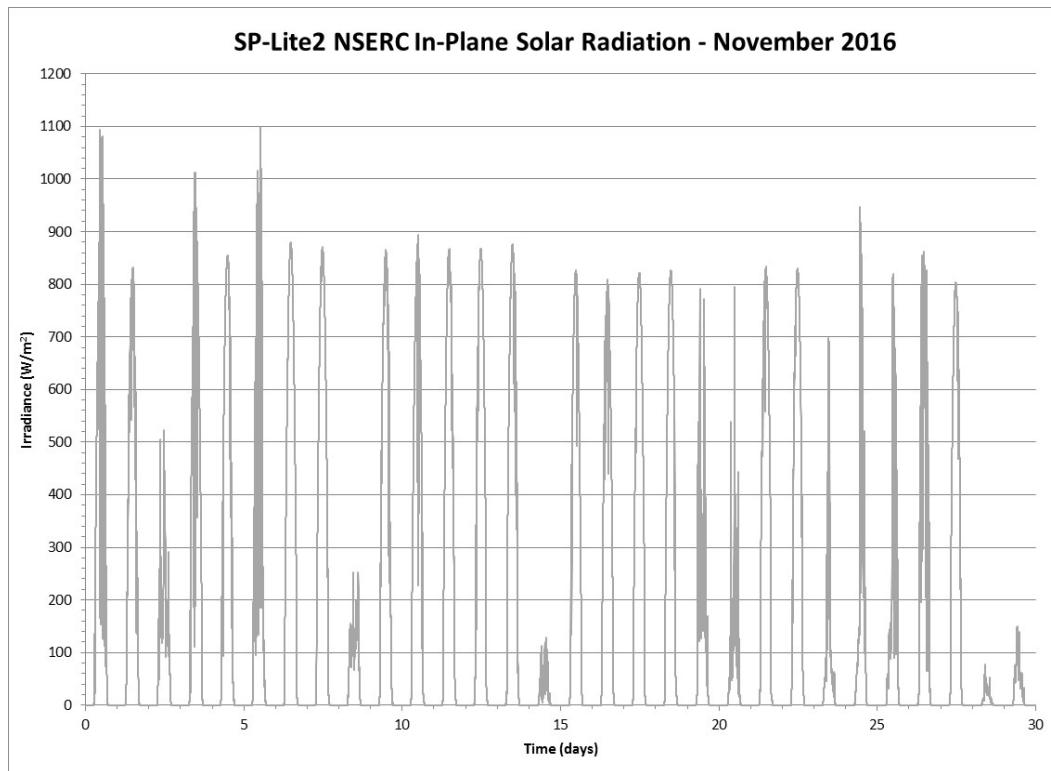


Figure 206 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for November 2016

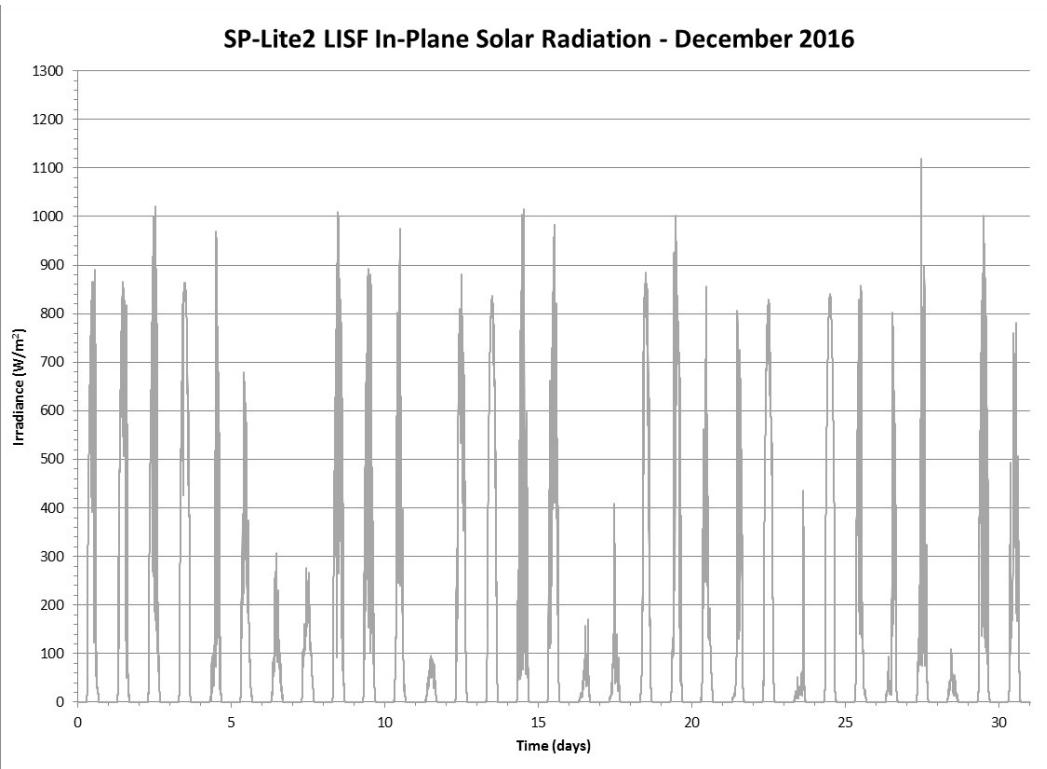


Figure 207 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for December 2016

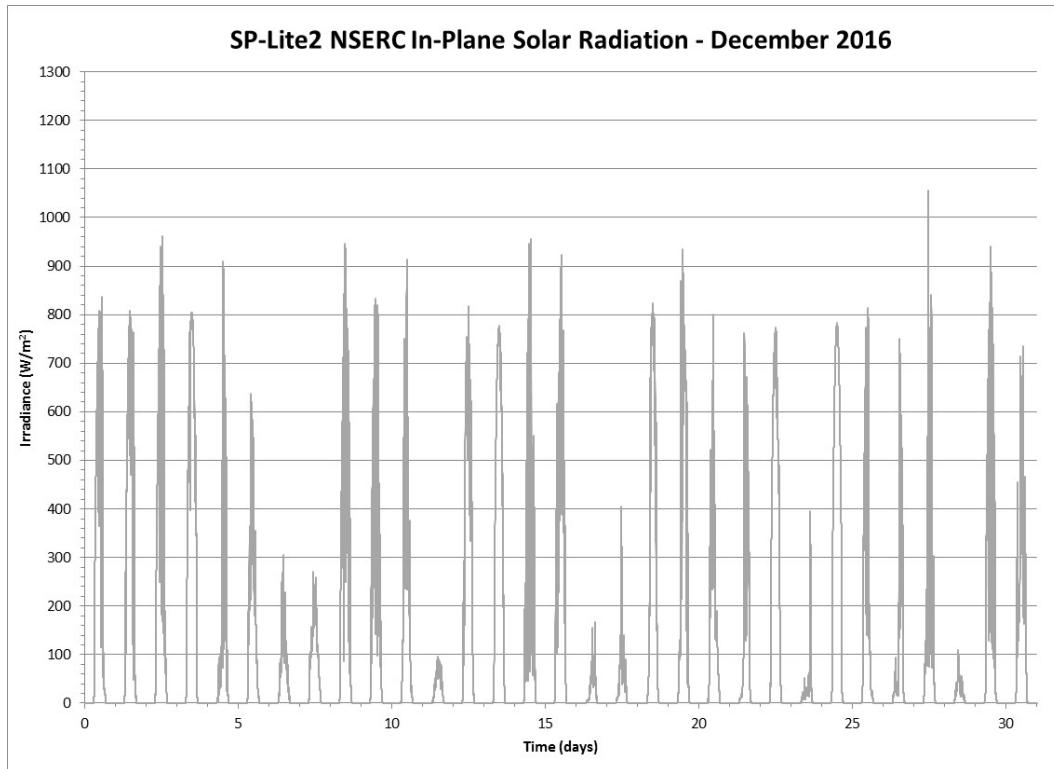


Figure 208 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for December 2016

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